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ABSTRACT

A major obstacle to the effective educational use of computers is the lack of a natural means of communication between the student and the computer. This report describes a technique for generating such natural language front-ends for advanced instructional systems. It discusses: (1) the essential properties of a natural language front-end, (2) some prior systems having some of the desired capabilities, and (3) the technical details underlying "semantic grammars." This last notion is introduced as a paradigm for organizing the knowledge required to understand language which permits efficient parsing. In semantic grammar, non-terminal categories are formed on conceptual rather than syntactic bases. This allows semantic knowledge to be integrated into the parsing process whenever it is beneficial. The ability of Augmented Transition Networks (ATN)-based semantic grammars to perform satisfactorily in an educational environment is demonstrated in the natural language front-end for the SOPHIE system. Appendices describe SOPHIE semantic grammar in two formalisms (ATN and BTN). (Author/DAG)

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SEMANTIC GRAMMAR: A TECHNIQUE FOR CONSTRUCTING NATURAL LANGUAGE INTERFACES TO INSTRUCTIONAL SYSTEMS

Richard R. Burton   John Seely Brown

May 1977

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One of the major stumbling blocks to the more effective educational use of computers is the lack of a natural means of communication between the student and the computer. This report addresses the problems of developing a system that can understand natural language (English) for advanced computer-based instructional systems. Training environments impose the following requirements on a natural language understanding system: (1) efficiency, (2) habitability, (3) self-teachability, and (4) awareness (OVER) of ambiguity. The major leverage points that allow these requirements to be met are: (1) limited domain, (2) limited activities within that domain, and (3) known conceptualizations of the domain. In other words, we must know the problem area, the type of problem the student is trying to solve and the way he should be thinking about the problem in order to solve it.

The notion of semantic grammar is introduced as a paradigm for organizing the knowledge required to understand language which permits efficient parsing. In semantic grammar, non-terminal categories are formed on conceptual rather than syntactic bases. This allows semantic knowledge to be integrated into the parsing process whenever it is beneficial. The semantic grammar also lends itself to a simple yet powerful method of handling pronominalizations, ellipses and other sentence fragments that arise naturally in a dialogue situation.

The need for a succinct formalism for expressing semantic grammars led to the use of the Augmented Transition Networks (ATN). The ability of ATN-based semantic grammars to perform satisfactorily in an educational environment is demonstrated in the natural language front-end for the SOPHIE system.

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ABSTRACT

One of the major stumbling blocks to the more effective educational use of computers is the lack of a natural means of communication between the student and the computer. This report addresses the problems of developing a system that can understand natural language (English) for advanced computer-based instructional systems. Training environments impose the following requirements on a natural language understanding system: (1) efficiency, (2) habitability, (3) self-teachability, and (4) awareness of ambiguity. The major leverage points that allow these requirements to be met are: (1) limited domain, (2) limited activities within that domain, and (3) known conceptualizations of the domain. In other words, we must know the problem area, the type of problem the student is trying to solve and the way he should be thinking about the problem in order to solve it.

The notion of semantic grammar is introduced as a paradigm for organizing the knowledge required to understand language which permits efficient parsing. In semantic grammar, non-terminal categories are formed on conceptual rather than syntactic bases. This allows semantic knowledge to be integrated into the parsing process whenever it is beneficial. The semantic grammar also lends itself to a simple yet powerful method of handling pronominalizations, ellipses and other sentence fragments that arise naturally in a dialogue situation.

The need for a succinct formalism for expressing semantic grammars led to the use of the Augmented Transition Networks (ATN). The ability of ATN-based semantic grammars to perform satisfactorily in an educational environment is demonstrated in the natural language front-end for the SOPHIE system.

Preface

With the advent of knowledge-based instructional systems that can answer trainees' questions, critique their hypotheses and automatically provide remedial hints, the need for a man-machine interface that facilitates rather than hinders a student's communication with the machine becomes ever more pressing. This report describes a general technique for generating "friendly", efficient and robust natural language front ends for advanced instructional systems. The generality of this technique has been proved by its successful application in a range of instructional systems; its efficiency has turned out to rival the keywords parsers which underly most of the classical CAI systems; its robustness has been attested to by the fact that it has been able to handle nearly every serious query posed to our electronic instructional systems in the course of a lesson or exercise.

In this report we first discuss the essential properties that comprise a "friendly" natural language front-end for an instructional system. Next, we discuss some prior systems that have some, but not all, of the desired capabilities and then we focus on the technical details underlying "semantic grammars" -- a new technique for producing the desired man-machine interfaces. Although there is little emphasis placed on the analysis of how students used the capabilities afforded by this kind of natural language interface (made possible by semantic grammars), a companion report contains the analysis of nearly twelve thousand natural language interactions collected from students using instructional systems built around this technique.

Chapter 1

REQUIREMENTS FOR A NATURAL LANGUAGE INTERFACE FOR INSTRUCTIONAL SYSTEMS

This research arose from the need for natural language interfaces to complex instructional systems which underly reactive training environments. As used here, the term "reactive training environment" refers to flexible problem solving, laboratory-like situations that have been implemented on a computer. The environment is reactive in the sense that the computer can (in addition to implementing the laboratory) monitor the student's activities and provide tutorial feedback during the solution of problems. A characteristic of such systems is that the computer-naive students are involved in a training situation in which the computer is merely the medium. Most certainly these students are not interested in state-of-art man-machine communication; they must be free to concentrate on solving their problems and learning from their solution paths and errors.

This instructional environment places constraints on a natural language understanding system that exceed the capabilities of all existing systems. These constraints include: (1) efficiency (2) habitability (3) self-teachability and (4) the ability to exist with ambiguity. In the remainder of this chapter we will explore why these are important, and then provide an overview of the remainder of this report.

Requirements

A primary requirement for a natural language processor, in an instructional situation, is speed. Imagine the following setting: the student is at a terminal actively working on a problem. He decides that he needs another piece of information to advance his solution, so he formulates a query. Once he has finished typing his question, he will wait for the system to give him an answer before he continues working on his solutions. During the time it takes the system to parse his query, the student is apt to forget pertinent information and lose interest. Psychological experiments have shown that response delays longer than two seconds have serious effects on the performance of complex tasks via terminals (Miller 68). In these two seconds, the system must understand the query; deduce, infer, lookup or calculate the answer; and generate a response.(1)

The second requirement for a natural language front-end is habitability. Any natural language system written in the forseeable future is not going to be able to understand all of natural language. What it must do is characterize and understand a useable subset of the language. Watt (1968 p. 338) defines a "habitable" sub-language as "one in which its users can express themselves without straying over the language boundaries into unallowed sentences". Very intuitively, for a system to be habitable it must, among other things, allow the user to make local or minor modifications to an accepted sentence and get another accepted sentence. Exactly how much modification constitutes a minor change has never been specified. Some examples may provide more insight into this notion.

(1) Is anything wrong?
(2) Is there anything wrong?
(3) Is there something wrong?
(4) Is there anything wrong with section 3?
(5) Does it look to you like section 3 could have a problem?

If a problem solving system accepts sentence 1, it should also accept the modifications given in sentence 2 and 3. Sentence 4 presents a minor syntactic extension which may have major repercussions in the semantics but which should also be accepted. Sentence 5 is an example of a possible paraphrase of sentence 4 which is beyond the intended notion of habitability. Based on the acceptance of sentences 1-4, the user has no reason to expect that sentence 5 will be handled.

Any sub-language which does not maintain a high degree of habitability is apt to be worse than no natural language capability at all. Because, in addition to the problem he is seeking information about, the student is faced, sporadically, with the problem of getting the system to understand his query. This second problem can be disastrous both because it occurs seemingly at random and because it is ill-defined. In an informal experiment to test the habitability of a system, the authors asked a group of four students to write down as many ways as possible of asking a particular question. The original idea was to determine how many of the various paraphrasing would be accepted. The students each came up with one phrasing very quickly but had tremendous difficulty thinking of any others, even though three of the first phrasings were different! This experience demonstrates the lack of student's ability to do "linguistic" problem solving and points out the importance of accepting the student's first phrasing.

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(1) Another effect of poor response time which is critical to intelligent monitoring systems is that more of the student's searching for the answer is done internally (i.e. without using the system). This decreases the amount of information the tutoring system receives and increases the amount of induction that must be performed, making the problem of figuring out what the student is doing much harder (e.g. the student won't "show his work" when solving a problem; he will just present the answer).

An equally important aspect of the habitability problem is the multi-sentence (or dialogue) phenomena. When students use a system that exhibits "intelligence" through its inference capabilities, they quickly start to assume that the system must also be intelligent in its conversational abilities as well. For example, they will frequently delete parts of their statements which they feel are obvious, given the context of the preceding statements. Often they are totally unaware of such deletions and show surprise and/or anger when the system fails to utilize contextual information as clearly as they (subconsciously) do. The use of context manifests itself in the use of such linguistic phenomena as pronominalizations, anaphoric deletions and ellipses. The following sequence of questions exemplifies these problems:

(6) What is the population of Los Angeles?
(7) What is it for San Francisco?
(8) What about San Diego?

The third requirement for a natural language processor is that it be self-teaching. As the student uses the system, he should begin to feel the range and limitations of the sub-language. When the student uses a sentence that the system can't understand, he should receive feedback that will enable him to determine why it can't. There are at least two kinds of feedback. The simplest (and most often seen) merely provides some indication of what parts of the sentence caused the problem (e.g. unknown word or phrase). A more useful kind of feedback goes on to provide a response based on those parts of the sentence that did make sense and then indicate (or give examples of) possibly related, acceptable sentences. It may even be advantageous to have the system recognize common unacceptable sentences and in response to them, explain why they are not in the sub-language. (See chapter 6 for further discussion of this point.)

The fourth requirement for a natural language system is that it be aware of ambiguity. Natural language gains a good deal of flexibility and power by not forcing every meaning into a different surface structure. This means that the program that interprets natural language sentences must be aware that more than one interpretation is possible. For example, when asked:

(9) Was John believed to have been shot by Fred?

one of the most potentially disastrous responses is "Yes". The user may not be sure whether Fred did the shooting or the believing or both. More likely, the user, being unaware of any ambiguity, assumes an interpretation that may be different than the system's. If the system's interpretation is different, the user thinks he has received the answer to his query when in fact he has received the answer to a completely independent query.

Either of the following is a much better response:

(10) Yes, it is believed that Fred shot John.
(11) Yes, Fred believes that John was shot.

The system need not necessarily have tremendous disambiguation skills, but it must be aware that mis-interpretations are possible and inform the user of its interpretation. In those cases where the system makes a mistake the results may be annoying but should not be catastrophic.

This report presents the development of a technique that we have named "semantic grammars" for building natural language processors that satisfy the above constraints. Chapter 2 discusses other systems which attack some of these problems. Chapter 3 presents a dialogue from the "intelligent" CAI system SOPHIE, that we used to refine and demonstrate this technique. This dialogue provides concrete examples of the kinds of linguistic capabilities that can be achieved using semantic grammars. Chapter 4 describes semantic grammar as it first evolved in SOPHIE, and points out how it allows semantic information to be used to handle dialogue constructs, and to allow the directed ignoring of words in the input. Chapter 5 discusses the limitations that were encountered in the evolution of semantic grammars in SOPHIE as the range of sentences was increased and how these might be overcome by using a different formalism -- augmented transition networks (ATN). Chapter 5 also reports on the conversion of the

SOPHIE semantic grammar to an ATN, and the extensions to the ATN formalism which were necessary to maintain the solutions presented in chapter 4. Chapter 5 also includes comparison timings between the two versions of the natural language processor. Chapter 6 describes experiences we have had with SOPHIE, and presents techniques developed to handle problems in the area of non-understood sentences. Chapter 7 suggests directions for future work.

Chapter 2

RELATED SYSTEMS

In this chapter we will describe a number of different techniques that have evolved from research in the area of natural language understanding as applied to practical tasks. Our purpose is to describe a set of techniques that have been developed to handle a natural language input throughout a range of complexity. We also seek to dispel the idea that there is a "natural language" as it applies to interfacing to computer systems, or that there exists one "best" technique for every application.

KEYWORD SCHEMES

Perhaps the oldest and simplest method of dealing with unrestricted natural language was through keyword parsing. The technique was introduced by Weizenbaum (1966a) and has been used and extended by others (e.g., Weizenbaum 1966b, Brown et al. 1973, Shapiro et al. 1975, Colby et al. 1974). Using this parsing scheme, an input sentence is searched for "key" words. Each keyword is associated with a collection of patterns that are then tested against the complete input. If a pattern matches, an action associated with that pattern (typically a reassembly rule which constructs an output sentence by reassembling pieces of input) is executed. This action represents the "meaning" of the sentence to the system (i.e. the sentence's semantics).

Keyword analysis schemes have the advantage of being fast and of allowing the user great freedom of expression since any number of extraneous words can be included as long as the keywords appear. A particular parser can also be changed easily (by adding new rules) until such time as the rules begin interacting, at which point it is unclear which rule to use. When interactions do begin to occur, keywords can be assigned an "importance" number and the rule with the highest number can be used. However, conflicts may still arise when different keywords of equal importance appear in the same sentence.

Keyword techniques work well in situations where the actions that the system wishes to take in response to a sentence correspond in a simple way to the words (i.e. the concepts are not typically expressed as multiple word phrases, and words do not have multiple interpretations). However, they are weak in situations in which concepts are complex enough to require embedding or in which quantification(2) is required, since their semantic interpretation is essentially one level. In these cases, keyword patterns become more cumbersome and inefficient to use than more structural techniques. For example, consider the sentence:

(1) I think Q5 has an open emitter and a shorted base collector junction.

To recognize this sentence requires a very detailed keyword pattern which could be "keyed" equally well, or equally poorly, off any of the words: think, Q5, open, emitter, shorted, base or collector. The main failing of the keyword technique is that it's incapable of capturing any of the structure of the language it is trying to characterize.

PARRY

PARRY is a ongoing project to develop a dialogue system that simulates paranoid behavior (Colby 1973, Colby et al. 1974). The system must respond to any possible question and must "understand" the questions well enough to exhibit paranoid behavior. To these ends, Colby has extended the keyword parsing techniques introduced by Weizenbaum by adding a second level of matching. After a preprocessing phase collapses compound words, canonicalizes similar words, performs minor spelling correction and deletes unrecognized words, the input is segmented at certain keyword boundaries.(3) Each segment is then matched against a collection of segment patterns. The resulting list of recognized segments is then matched to a collection of complex patterns. Patterns have reassembly rules associated with them that construct the response.

Two important restrictions that should be placed on the application of keyword schemes to avoid mis-understandings (i.e. to avoid having patterns apply when they shouldn't) have arisen from Colby's work. One is that, at

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(2) Quantification refers to the problem of having a noun phrase that can range over a set of values, e.g. "some cars have engines", "all cars have engines". One of the problems with quantification is determining the scope of the quantification with respect to the rest of the sentence, especially when the rest of the sentence contains another quantifier.

(3) The fragmentation technique (which is critical to proper operation) was developed by Wilks working in machine translation (1973a, 1973b). The list of segmentation words includes punctuation marks, subjunctives, conjunctions and prepositions.

most, one element should be ignored at each level of matching. Segment matches should account for all but one word. Complex patterns should account for all but one segment. The other restriction is that patterns should require that their elements occur in a particular order. The following example (from Colby et al. 1974) demonstrates the usefulness of ignoring words such as "well" in sentence 3, and the importance of word order; without word order restrictions, any pattern that matched 2 would also match 3.

(2) Are you well?
(3) Well, are you?

PARRY has demonstrated the capability of dealing with a relatively large number of concepts at a shallow level. The power in PARRY's approach lies in its ability to tolerate unknown words. As mentioned, this fuzziness is implemented by allowing the deletion of single elements from both levels of matching. Unfortunately the underlying semantics of PARRY's task, indeed the goals of the task itself, are vague, which makes attributes such as scope and habitability hard to evaluate. Furthermore, the two-level pattern matching technique lacks the precision required in a problem solving situation in which many regularities cannot be captured by one-level embedding.

NLPQ

Heidorn (1972,1974,1975) developed an automatic programming system called NLPQ which allows users to describe simulation problems in English. The system takes an English partial description of a problem and fits it into an internal description language, building pieces of the problem. From the partial internal description, questions are generated that request missing pieces of information. When the description is complete, the system can generate a GPSS program or an English description of the model it has built from the user's description. The user can also ask questions about the present model, and make changes and additions to it. The English processing is done using augmented phrase structure rules. The phrase structure component is syntax-based -- it looks for things like noun phrases -- with semantic restrictions being carried along in features that are tested in conditions on the phrase structure rules. The structure building augmentations create semantic/conceptual network structures, called segments, that represent the semantics of the phrase. Much of the system's success appears to be its close match between the structure of segments and the way English is used to describe modelling problems. No information on the use of NLPQ by naive users has been published, so it is difficult to evaluate the system's habitability.

CONSTRUCT

CONSTRUCT is a general system to do natural language processing developed at the Institute for Mathematical Studies in the Social Sciences at Stanford University (Smith et al. 1974). Its major application is in a text-based, question answering system for elementary mathematics (Smith, N.W. 1974). The system answers questions such as:

(4) Are there any even prime numbers that are greater than 2?

(5) Is the sum of 5 and 2 less than the product of 5 and 2 but greater than the difference of 5 and 2?

The semantic basis of the system is a collection of procedures for generating and manipulating sets and numbers. The semantics of question 4 would be "are there any elements in the set created by intersecting the set of even numbers, the set of prime numbers and the set of numbers greater than 2?" As all of the sets in the example are infinite, the procedures know about dealing with intensional as well as extensional descriptions of sets.

The meaning of a sentence is determined by the following process. First a preprocess phase occurs during which (1) abbreviations are expanded, (2) synonyms are canonicalized, (3) compound word and common phrases are collapsed to a single word representation, (4) noise words are eliminated and (5) each word is replaced by its lexical category. The input is then parsed with a context-free grammar with the semantic interpretation occurring in parallel via semantic construction functions associated with each grammar rule. Whereas this procedure is clearly inadequate if a traditional syntactic grammar is used -- no reasonable semantic function could be associated with the rule S := NP VP -- the CONSTRUCT grammar is built around the semantic rules using categories that capture concepts in the application domain. For example, the grammar contains the grammatical category SUBST which corresponds to the semantic concept of a constructive set. This cuts across traditional category boundaries as seen in the sentences from (Smith et al. 1974):

Is 2 a factor of 4?
How many factors of 12 are even?
Give me the factors of 12 that are between 1 and 6.

The underlined portions would all be parsed into the SUBST category, although their traditional categories would be noun phrase, adjective, and prepositional phrase.

RENDEZVOUS

Codd (1974) is designing a natural language system, called RENDEZVOUS, to support the needs of casual users of data bases. One problem that Codd has addressed, which has been neglected in previous systems, is what action to take if a user's query is beyond the restricted language understood by the system. A central notion to Codd's proposed solution to this problem is that of a "clarification dialogue" -- a system initiated dialogue that includes queries about an unacceptable utterance that attempts to arrive at the user's meaning. Codd points out that a clarification dialogue must be embarked upon very carefully. For example, if the system encounters the unknown word "concerning", one of the worst possible responses is "What do you mean by the word 'concerning'?" Almost any response to such a question would be beyond the capabilities of the system. Any clarification dialogue must be of "bounded scope" and guided by those parts of the query which the system can understand. RENDEZVOUS also employs re-statement of a user's query to confirm the intent of the query and to point out ambiguities. The range of language accepted by RENDEZVOUS, indeed even the method used to extend the range, is unclear. The aspect of RENDEZVOUS that is of interest here is the extent to which it has been designed as a "friendly" system.

LUNAR

The LUNAR system (Woods 1973a; Woods et al. 1972) is a natural language understanding implementation that combines a general semantic interpretation mechanism (Woods 1967,1968) with a large scale grammar of English (Woods 1970; Woods et al. 1972). LUNAR was designed to allow a lunar geologist to use English to query the chemical analysis data collected from the moon missions. Typical questions the system answers are:

> What is the average concentration of aluminium in high alkali rocks?
> Which samples have greater than 20% modal Plagioclase?

The processing of a query occurs in three major phases. During the first phase, the syntactic component derives the "deep structure" of the sentence.(4) The syntactic component uses a general transformational grammar of English syntax expressed as an augmented transition network (see Chapter 5). In the second phase a general, rule-driven semantic interpretation procedure produces the representation of the meaning of the sentence as a program in a formal retrieval language.(5) The semantic interpretation rules are tree-structured pattern-matching rules that are used in groups to extract the meaning of different pieces of the syntax tree. The third phase is the execution of the formal expression to produce the answer to the request. The formal query language is a generalization of the predicate calculus that has been carefully designed to allow natural translation from English. The strength of the LUNAR system lies in its mechanisms to deal with quantification, conjunction, and relative clauses, and these are direct results of the carefully designed formal query language.

Discussion

The notion of an augmented phrase structure grammar provides a useful base for comparison between these systems.(6) An augmented phrase structure grammar contains two components. One is a set of context-free phrase structure rules. The other is a corresponding set of functions, sometimes arbitrary, sometimes restricted, augmenting each of the rules that can be used to block the application of the context-free rules and to maintain structures. While the paradigm of augmenting phrase structure grammars is followed by a large number of natural language systems, important differences exist with respect to what type of information is encoded in the grammar. For example, the LUNAR system uses a purely syntactic grammar(7) and uses the augments to perform syntactic operations such as subject-verb agreement and to maintain the structure of the syntactic tree. NLPQ uses a syntactic grammar restricted by usually semantic features and uses the augments to perform parallel semantic interpretation. CONSTRUCT performs the semantic interpretation in parallel with a set of context-free rules that are semantically oriented. PARRY's patterns, if viewed as limited, phrase-structure grammar rules, are directly linked to the semantics of the system. The decision about how much semantic information to encode in the grammar is a trade-off between efficiency and generality. Each of the systems presented here represents a defensible position along this spectrum.

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(4) This is the linguistic deep structure hypothesized by Chomsky (Chomsky 1965) which has a central role in the theory of transformational grammar.
(5) The notion that the meaning of a sentence is a program is generally called "procedural semantics". Procedural semantics is in general use for question answering applications. It does not, however, constitute a complete theory of meaning. In particular it does not account for such phenomena as declaratives, uses of temporal references, and belief structures.
(6) The idea of associating additional information with a phrase structure grammar has appeared in various forms since early compiling systems (Irons 1961).

When we began developing the SOPHIE system(8) we explored the possibility of using, intact, the syntactic component of the LUNAR system. Since the LUNAR syntactic component was building a linguistically motivated description, as opposed to the task oriented descriptions being built by the other systems, we felt its transferability to other domains would be high. We found the grammar to be very adequate, parsing many of the most complicated sentences we felt SOPHIE would ever need to understand. Unfortunately, on simple sentences it provided more information about the sentence than we needed. For example, tense information was seldom needed and in those cases where needed, it could be extracted from the relationships between concepts. The quantification and relative clause mechanisms were oriented towards Woods' formal query language which was not natural for our use. The use of conjunction in our domain is straightforward and relatively predictable, unlike its use in the LUNAR domain. All in all we had the feeling of using a microscope when we only needed a magnifying glass! The underlying semantic structure of our system could not take advantage of such detail. Added detail is acceptable (it can always be ignored) except that the perception of such detail takes time, which is a scarce commodity. The LUNAR system was taking 2 or 3 seconds to syntactically parse a sentence and another 5 to semantically interpret it. This experience led us to explore ways in which the semantics of the system could be used to speed the understanding process.

---

(7) The augmented transition network is an extension of a recursive transition network that has the power of a phrase structure grammar. For this reason we can classify it here as using an augmented phrase structure grammar. We will argue later that the transition network has conceptual advantages over phrase structure rules, but this does not affect this discussion which points out the difference in the kind of information captured in the grammar.

(8) A SOPHisticated Instructional Environment for teaching electronic troubleshooting. Chapter 3 provides examples of SOPHIE's language requirements.

The technique we developed (described in Chapter 4) has much in common with both NLPQ and CONSTRUCT. However, significant differences arise from the emphasis we have placed on dealing with dialogues, and on the construction of a friendly system. This has caused us to exploit two uses of semantics (during parsing) not found in these other systems. One is the insight provided into the nature of ellipsis and deletion in dialogues. The other is the basis provided for characterizing a habitable language. In Chapter 4, we shall discuss our concept of a semantic grammar and how it allows exploitation of these two advantages. Before we get into the details of how this is accomplished, we present in the next chapter an example of what has been accomplished.

Chapter 3

SAMPLE DIALOGUE

Before delving into the structural aspects and technical details of the semantic grammar technique, we would first like to provide a concrete example of the dialogues it has supported. This chapter presents an annotated dialogue of a student using the "Intelligent" CAI system SOPHIE.(9) SOPHIE was developed to explore the use of artificial intelligence techniques in providing tutorial feedback to students engaged in problem solving activities. The particular problem solving activity that SOPHIE is concerned with is the troubleshooting of a malfunctioning piece of electronic equipment. SOPHIE models the piece of equipment and answers the student's requests for measurements and other information to aid him in debugging the equipment. More important, throughout the problem solving session, SOPHIE can evaluate the logical consistency of a student's hypothesis or generate hypotheses which are consistent with the behavior the student has thus far observed.(10) In the dialogue, the student's typing is underlined. Even though the dialogue deals with electronic jargon, the linguistic issues it exemplifies occur in all domains. The annotations (lower case, indented) attempt to point out these problems and should be understandable to the non-electronics oriented reader.

```
WELCOME TO SOPHIE - A SIMULATED ELECTRONICS LABORATORY.
```

> The circuit (Figure 3.1) is based on the Heathkit IP-28 power supply. The IP-28 is a reasonably sophisticated power supply with both current limiting and voltage limiting behavior. These two interrelated feedback loops make troubleshooting this circuit non-trivial.

```
>>INSERT A FAULT
```

> The student tells SOPHIE to give him a fault which he can troubleshoot. SOPHIE randomly selects a fault, inserts it into a model of the instrument and tells the student how the front panel controls are presently set.

```
THE INSTRUMENT HAS A FAULT AND ITS PRESENT CONTROL SETTINGS ARE:
CC        1.0       CURRENT CONTROL-FROM 0.0 (MIN CURRENT) TO 1.0
CR        HIGH      CURRENT RANGE SWITCH, HIGH=1 AMP, LOW=.1 AMP
LOAD      1000      LOAD RESISTANCE IN OHMS
VC        1.0       VOLTAGE CONTROL-FROM 0.0 (MIN VOLTAGE) TO 1.0
VR        HIGH      VOLTAGE RANGE SWITCH, HIGH=30, LOW=10 VOLTS
```

---

(9) The dialogue is intended to demonstrate SOPHIE's linguistic capabilities and, while it touches upon the major features of SOPHIE, it is not meant to exhibit the logical or deductive capabilities the system.

(10) The reader is encouraged to see (Brown and Burton 1975) for further examples and descriptions of SOPHIE's tutorial and inferential capabilities.

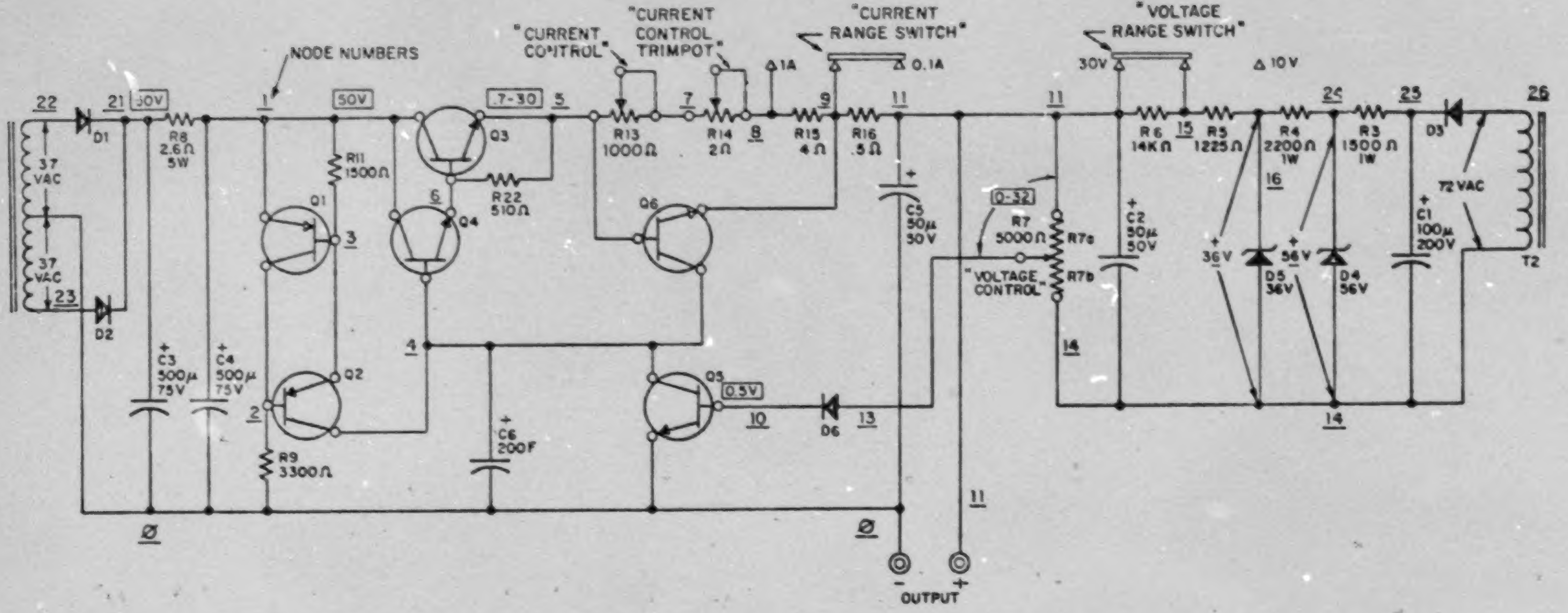

"CURRENT CONTROL"
"CURRENT CONTROL TRIMPOT"
"CURRENT RANGE SWITCH"
"VOLTAGE RANGE SWITCH"
NODE NUMBERS
22
21
50V
D1
37 VAC
37 VAC
23
D2
R8 2.6Ω 5W
C3 500μ 75V
C4 500μ 75V
1
50V
R11 1500Ω
Q1
3
Q2
2
R9 3300Ω
Q3
.7-30
5
R22 510Ω
6
Q4
4
C6 200F
Q6
Q5
0.5V
10
D6
13
R13 1000Ω
7
R14 2Ω
8
1A
R15 4Ω
9
R16 .5Ω
0.1A
11
C5 50μ 50V
0
11
OUTPUT
- +
0
11
0-32
R7 5000Ω
R7a
R7b
"VOLTAGE CONTROL"
14
30V
C2 50μ 50V
R6 14KΩ
15
R5 1225Ω
10V
36V
D5 36V
16
R4 2200Ω 1W
24
56V
D4 56V
R3 1500Ω 1W
25
C1 100μ 200V
D3
72 VAC
26
T2
14

Figure 3.1

Circuit Schematic of Heathkit IP-28 Power Supply

```
>>WHAT IS THE OUTPT?
OUTPT => OUTPUT
THE OUTPUT VOLTAGE IS 1.2 VOLTS.
```

SOPHIE corrects the student's typing mistake. Notice that "the output" was disambiguated as the output voltage.

```
IF YOU ARE NOT SURE WHETHER A VALUE IS CORRECT, YOU CAN ASK "IS THAT
VALUE CORRECT?"
```

The system points out a feature that the student may not otherwise be aware of. "Correct" here means what it is in a working instrument.

```
>>IS THAT RIGHT
IN A WORKING CIRCUIT THE OUTPUT VOLTAGE IS 30.1 VOLTS.
THAT VALUE IS INCORRECT.
```

"That" here refers to the value of the previous measurement. SOPHIE, in addition to the faulted instrument, has a working circuit which can be used to take reference measurements.

```
>>WHAT IS THE VOLTAGE BETWEEN THE CURRENT LIMITING TRANSISTOR
 ...AND THE CONSTANT CURRENT SOURCE?
THE VOLTAGE AT N4 IS 2.48 VOLTS.
```

In addition to specific part names, SOPHIE recognizes references to parts by their section. Notice that although the sentence says "voltage between x and y", it really means "voltage at z with respect to ground". The output routines rephrase the input in a simpler form (i.e. between x and y reduces to N4).

```
>>WHAT IS IT BETWEEN THERE AND THE BASE OF Q6
THE VOLTAGE BETWEEN N4 AND N5 IS 1.28 VOLTS.
```

Here "it" refers to "the voltage" and "there" refers to N4. Also notice that "between" has to be treated differently, i.e. two nodes are explicit now.

```
>>IS THERE ANY RIPPLE IN THE VOLTAGE AT THE BASE OF Q4?
I'M SORRY, I DO NOT HANDLE AC CHARACTERISTICS.
```

SOPHIE recognizes that the student is moving into an area that it is unable to handle. This is currently done by keyword recognition (e.g. ripple) but points out a technique that should be incorporated in other aspects of the system as well.

```
>>WHAT IS THE BASE CURRENT OF Q3
THE BASE CURRENT OF Q3 IS 12 MICROAMPS.
```

SOPHIE can answer questions about current, resistance, and power dissipation as well as voltage. The output and input routines know about unit prefixes.

```
>>THRU THE EMITTER?
THE EMITTER CURRENT OF Q3 IS -.26 MILLIAMPS.
```

This is a type of sentence fragment that occurs frequently in dialogues that we will refer to as an ellipsis. Rather than specifying a complete thought, an ellipsis only gives that piece of the thought which contrasts an earlier thought. Notice that the referent cannot be determined on syntactic grounds (as is possible with the ellipsis "the emitter current"; yet this is the sort of statement a student might make if the last answer had caused a slight shifting of his thinking.

```
>>COULD THE PROBLEM BE THAT Q5 IS BAD?
PLEASE BE MORE SPECIFIC ABOUT HOW Q5 IS FAULTED.
```

The student develops an idea about what is wrong and asks to have it evaluated.

```
>>COULD IT BE SHORTED?
THE SHORTED MODES OF A TRANSISTOR CURRENTLY IMPLEMENTED ARE: ALL
JUNCTIONS SHORTED OR ONE JUNCTION SHORTED WITH THE OPPOSITE
TERMINAL MODELLED OPEN.
```

A hypothesis must be completely (or non-ambiguously) specified before evaluation can take place. Even though the last statement generated an error condition, it is still used to determine possible pronoun referents.

```
SHOULD Q5 HAVE ALL JUNCTIONS SHORTED?
> NO
WHICH TERMINAL SHOULD BE MODELLED OPEN?
> THE BASE
OK, I'LL LET Q5 HAVE ITS EMITTER COLLECTOR JUNCTION SHORTED AND ITS BASE OPEN
```

At this point, SOPHIE looks back over the student's measurements to determine if he should have "known better". See (Brown and Burton 1975) or (Brown et al. 1975) for further description.

```
HMMM, LET ME COMPUTE ON THAT FOR A MINUTE.
```

When the system knows there maybe a long wait, a "delaying" message is printed to let the student know something is happening.

```
WHEN THE SETTINGS WERE:
     CC=1.0, CR=HIGH, LOAD=1000, VC=1.0, VR=HIGH,
THAT FAULT CONFLICTS WITH THE FOLLOWING MEASUREMENT.
YOU OBSERVED THAT THE VOLTAGE BETWEEN N4 AND N5 WAS 1.28 VOLTS.
IF Q5 HAD ITS EC SHORTED AND ITS BASE OPEN IT WOULD BE 1.1 MILLIVOLTS.
IN A WORKING CIRCUIT IT IS 1.43 VOLTS.

BUT THAT FAULT DOES EXPLAIN THE VALUES YOU OBSERVED FOR
THE OUTPUT VOLTAGE, THE VOLTAGE AT N4, THE VOLTAGE BETWEEN N4 AND N10,
THE EMITTER CURRENT OF Q3 AND THE BASE CURRENT OF Q3.

>>WHAT COULD BE WRONG
```

The student cannot go further and asks for assistance. SOPHIE proposes some possible hypotheses for the student to explore.

```
THERE ARE LOTS OF FAULTS WHICH WOULD EXPLAIN THE MEASUREMENTS YOU
HAVE TAKEN. HERE ARE SOME POSSIBILITIES:
THE RESISTANCE OF R8 CHANGES
THE LEAKAGE RESISTANCE OF C4 CHANGES
THE BETA OF Q3 CHANGES
R15 IS OPEN
Q6 IS FAULTED

>>IF R8 WERE 30K, WHAT WOULD THE OUTPUT VOLTAGE BE?
IF THE VALUE OF R8 WERE 30000
UNDER THE PRESENT SETTINGS, THE OUTPUT VOLTAGE WOULD BE .904 VOLTS.
IN A WORKING CIRCUIT IT IS 30.1 VOLTS.
```

The student doesn't believe one of the possibilities so he checks it using a hypothetical statement. Even though the voltage in this case and that in the case of a faulted circuit are not the same, they qualitatively agree.

```
>>REPLACE Q6
```

The student guesses maybe Q6 is bad and tries to replace it. When the student replaces a part SOPHIE queries him to insist that he know how it is faulted.

```
I AM GOING TO ASK YOU SOME QUESTIONS ABOUT HOW Q6 IS FAULTED.
ARE ANY JUNCTIONS SHORTED?
> YES
WHICH JUNCTIONS ARE SHORTED?
> ALL
```

If the response to a query is not understood, further specification of the expected response is given.

```
PLEASE SPECIFY THE JUNCTIONS AS EC EB AND CB (SEPARATED BY SPACES).
WHICH JUNCTIONS ARE SHORTED?
> EC EB AND CB
Q6 IS NOT FAULTED IN THAT MANNER.
```

The part would be replaced if any of the junctions had been shorted. SOPHIE would normally have critiqued the student's hypothesized fault. This was not included in the dialogue to save space.

```
Q6 NOT REPLACED.

>>VOLTAGE DROP ACROSS R5
THE VOLTAGE ACROSS R5 IS -.028 MILLIVOLTS.
```

Some noun phrase utterances are recognized as questions.

```
>>WHAT ABOUT R3?
THE VOLTAGE ACROSS R3 IS 71.6 VOLTS.
```

Another ellipsis. The context of the previous question is used to determine "what" about R3.

```
>>REPLACE R3
IS R3 OPEN OR SHORTED OR DOES IT HAVE THE WRONG VALUE?
> IT IS OPEN
R3 REPLACED

>>IS THERE ANYTHING ELSE WRONG
NO
```

After fixing the fault, the student uses SOPHIE to explore other aspects of the circuit's behavior.

```
>>IF C2 WERE LEAKY, WHAT WOULD THE VOLTAGE ACROSS IT BE?
```

The referent to "it" in this case occurs earlier in the same sentence.

```
IS IT OKAY IF I USE 10000 FOR THE LEAKAGE RESISTANCE OF C2?
> YES
IF THE LEAKAGE RESISTANCE OF C2 WERE 10000
UNDER THE PRESENT SETTINGS, THE VOLTAGE ACROSS C2 WOULD BE 26.3 VOLTS.
IN A WORKING CIRCUIT IT IS 28.9 VOLTS.

>>WHAT HAPPENS IF C1 SHORTS?
UNDER THE SETTINGS:
        CC=1.0, CR=HIGH, LOAD=1000, VC=1.0, VR=HIGH,
IF C1 WERE SHORTED, D3 WOULD BECOME OVERLOADED.
```

In the case where nothing more interesting happens, "what happens" questions default to the output voltage.

```
>>IF Q6 HAS AN OPEN EMITTER AND A SHORTED BAE COLLECTOR JUNCTION
 ...WHAT HAPPENS TO THE VOLTAGE BETWEEN ITS BASE AND THE JUNCTION OF
```

```
...THE VOLTAGE LIMITING SECTION AND THE VOLTGEA REFERENCE SOURCE?
BAE => BASE
VOLTGEA => VOLTAGE
```

Several examples of the use of conjunction. Imagine the student's frustration if he is forced to type this query over because of spelling mistakes.

```
IF Q6 HAD ITS BASE COLLECTOR JUNCTION SHORTED AND ITS EMITTER OPEN,
UNDER THE PRESENT SETTINGS:
      CC=1.0, CR=HIGH, LOAD=1000, VC=1.0, VR=HIGH
THE VOLTAGE BETWEEN N5 AND N13 WOULD BE THE SAME, I.E. 28.9 VOLTS.
```

A hypothetical question is first tried under the present settings. If no difference is noted, other settings are tried.

```
LET ME TRY ANOTHER CASE WHICH USUALLY POINTS OUT PROBLEMS IN THAT
SECTION OF THE CIRCUIT.
UNDER THE SETTINGS:
      CC=.9, CR=LOW, LOAD=10, VC=1.0, VR=LOW,
THE VOLTAGE BETWEEN N5 AND N13 WOULD BE 8.94 VOLTS.
IN A WORKING CIRCUIT IT IS 9.57 VOLTS.

>>WHAT IS THE OUTPUT VOLTAGE WHEN THE VOLTAGE CONTROL IS SET TO .5?
WITH THE VOLTAGE CONTROL NOW SET AT .5
THE OUTPUT VOLTAGE IS 15.6 VOLTS.
```

A hypothetical question can involve the changing of a control. If this happens the control is left at the new setting and the student is told so.

```
>>IF IT IS SET TO .7?
WITH THE VOLTAGE CONTROL NOW SET AT .7
THE OUTPUT VOLTAGE IS 21.4 VOLTS.
```

Context determines which measurement should be taken and which control should be set.

```
>>.9?
WITH THE VOLTAGE CONTROL NOW SET AT .9
THE OUTPUT VOLTAGE IS 27.2 VOLTS.

>>WHAT IS THE CURRENT THRU THE CC WHEN THE VC IS SET TO 1.0?
WITH THE VOLTAGE CONTROL NOW SET AT 1.0
THE CURRENT THRU THE CURRENT CONTROL IS 30 MILLIAMPS.
```

CC and VC are abbreviations. Notice that controls are also "parts" that can be used in measurements.

```
>>WHAT IS IT WITH IT SET TO .8?
WITH THE VOLTAGE CONTROL NOW SET AT .8
THE CURRENT THRU THE CURRENT CONTROL IS 24 MILLIAMPS.
```

Here the system must correctly instantiate two occurrences of "it". The referent to the second "it" could be either CC or VC since these are both controls.

```
>>GOODBYE
GOODBYE
```

Chapter 4

SEMANTIC GRAMMAR

INTRODUCTION

In Chapter 1 we described the requirements for a natural language processor in a learning environment. Briefly, they are efficiency and friendliness over the class of sentences that arise in a dialogue situation. The major leverage points we have that allow us to satisfy these requirements are (1) limited domain, (2) limited activities within that domain, and (3) known conceptualizations of the domain. In other words, we know the problem area, the type of problem the student is trying to solve, and the way he should be thinking about the problem in order to solve it. What we are then faced with is taking advantage of these constraints in order to provide an effective communication channel.

Notice that all of these constraints relate to concepts underlying the student's activities. In SOPHIE, the concepts include voltage, current, parts, transistors, terminals, faults, particular parts (e.g. R9, Q5, etc.), hypotheses, controls, settings of controls, and so on. The (dependency) relationships between concepts include things such as: voltage can be measured at terminals, parts can be faulted, controls can be set, etc. The student, in formulating a query or statement, is requesting information or stating a belief about one of these relationships (e.g. "What is the voltage at the collector of Q5" or "I think R9 is open".) It occurred to us that the best way to characterize the statements used for this task was in terms of the concepts themselves as opposed to the traditional syntactic structures. The language can be described by a set of grammar rules that characterize, for each concept or relationship, all of the ways of expressing it in terms of other constituent concepts. For example, the concept of a measurement requires a quantity to be measured and something against which to measure it. A measurement is typically expressed by giving the quantity followed by a preposition, followed by the thing that specifies where to measure (e.g. "voltage across C2", "current thru D1", "power dissipation of R9", etc.) These phrasings are captured in the grammar rule:(11)

<MEASUREMENT> := <MEASUREABLE/QUANTITY> <PREP> <PART>

The concept of a measurement can, in turn, be used as part of other concepts, e.g. to request a measurement "What is the voltage across C2?"; or to check a measurement "Is the current thru D1 correct?". We call this type of grammar a "semantic grammar" because the relationships it tries to characterize are semantic/conceptual as well as syntactic.

Semantic grammars have two advantages over traditional syntactic grammars. They allow semantic constraints to be used to make predictions during the parsing process, and they provide a useful characterization of those sentences that the system should try to handle. The predictive aspect is important for four reasons: (1) It reduces the number of alternatives that must be checked at a given time; (2) it reduces the amount of syntactic (grammatical) ambiguity; (3) it allows recognition of ellipsed or deleted phrases; and (4) it permits the parser to skip words at controlled places in the input (i.e. it enables a reasonable specification of control). These points will be discussed in detail in a later section.

The characterization aspect is important for two reasons: (1) It provides a handle on the problem of constructing a habitable sub-language. The system knows how to deal with a particular set of tasks over a particular set of objects. The sub-language can be partitioned by tasks to accept all straightforward ways of expressing those tasks, but does not need to worry about others; (2) It allows a reduction in the number of sentences that must be accepted by the language while still maintaining habitability. There may be syntactic constructs that are used frequently with one concept (task) but seldom with another. For example, relative clauses may be useful in explaining the reasons for performing an experimental test but are an awkward (though possible) way of requesting a measurement. By separating the processing along semantic grounds, one may gain efficiency by not having to accept the awkward phrasing.

---

(11) This is not actually a rule from the grammar but is merely intended to be suggestive.

Representation of Meaning

Since natural language communication is the transmission of concepts via phrases, the "meaning" of a phrase is its correspondent in the conceptual space. The entities in SOPHIE's conceptual space are objects, relationships between objects, and procedures for dealing with objects. The meaning of a phrase can be a simple data object (e.g. "current limiting transistor") or a complex data object (e.g. "C5 open", "Voltage at node 1"). The meaning of a question is a call to a procedural specialist that knows how to determine the answer. The meaning of a command is a call to a procedure that performs the specified action.(12) For example, the procedural specialist DOFAULT knows how to fault the circuit and is used to represent the meaning of commands to fault the circuit (e.g. "Open R9", "Suppose C2 shorts and R9 opens"). The argument that DOFAULT needs in order to perform its task is an instance of the concept of faults that specifies the particular changes to be made, e.g. "R9 being open". These same concepts of particular faults also serve as arguments to two other specialists: HYPTEST which determines the consistency of a fault with respect to the present context, e.g. "Could R9 be open"; and SEEFAULT which checks the actual status of the circuit, e.g. "Is R9 open?".

Result of the Parsing

Basing the grammar on conceptual entities allows the semantic interpretation (the determination of the concept underlying a phrase) to proceed in parallel with the parsing. Since each of the non-terminal categories in the grammar is based on a semantic unit, each grammar rule can specify the semantic description of a phrase that it recognizes in much the same way that a syntactic grammar specifies a syntactic description. The construction portion of the rules is procedural. Each rule has the freedom to decide how the semantic descriptions, returned by the constituent items of that rule, are to be put together to form the correct "meaning".

---

(12) Declarative statements are treated as requests because the pragmatics of the situation imply that the student is asking for verification of his statement. For example, "I think C2 is shorted" is taken to be a request to have the hypothesis "C2 is shorted" critiqued.

For example, the meaning of the phrase "Q5" is the data base object Q5. The meaning of the phrase "the collector of Q5" is (COLLECTOR Q5) where COLLECTOR is a function that returns the data base item that is the collector of the given transistor. For a more complicated example, consider the non-terminal <MEASUREMENT> shown in Figure 4.1.

Figure 4.1

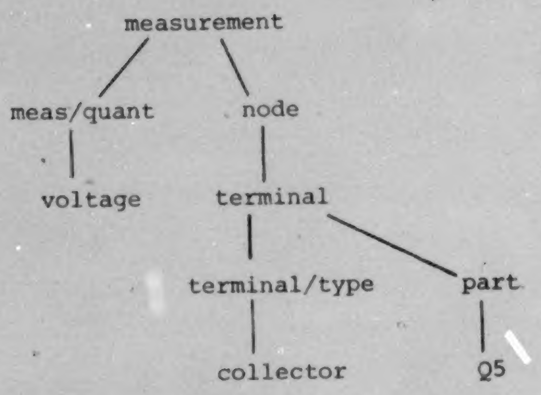
A Semantic Grammar Rule(13)

```
<MEASUREMENT>  := output <MEAS/QUANT> [of <TRANSFORMER>] !
                  <TRANSFORMER> <MEAS/QUANT> !
                  <MEAS/QUANT> between <NODE> and <NODE> !
                  <MEAS/QUANT> <PREP> <PART> !
                  <MEAS/QUANT> between output terminals !
                  <MEAS/QUANT> <PREP> <JUNCTION> !
                  <MEAS/QUANT> <PREP> <NODE> !
                  <JUNCTION/TYPE> <MEAS/QUANT>
                      of <TRANSISTOR/SPEC> !
                  <TRANSISTOR/TERM/TYPE> <MEAS/QUANT>
                      of <TRANSISTOR>
```

The goal for this non-terminal is to capture all of the ways that a student can specify a measurement (voltage across D3, output current, etc.). To specify a measurement, there must be a quantity to be measured <MEAS/QUANT> (e.g. voltage, current, resistance, power dissipation), and something to measure (e.g. with respect to a part, <PART/SPEC>; a transistor junction, <JUNCTION>; or possibly a point in the circuit, <NODE>). The rule for <MEASUREMENT> expresses all of the ways that the student can give a measurable quantity and also supply its required arguments. The structure which results from <MEASUREMENT> is a function call to the function MEASURE which supplies the quantity being measured and other arguments specifying where to measure it. Thus the meaning of the phrase "the voltage at the collector of Q5" is (MEASURE VOLTAGE (COLLECTOR Q5)) which was generated from the control structure:

---

(13) The rule is expressed in a BNF-like notation which is an abstraction of the actual rule (see next section). Non-terminals are in capital letters and enclosed in angle brackets. Terminal are in lower case. Brackets enclose optional elements. Alternative right hand sides are separated by a "!".



A careful examination of Figure 4.1 reveals that <MEASUREMENT> also accepts "meaningless" phrases such as "the power dissipation of Node 4." In addition, it accepts some meaningful phrases such as "the resistance between Node 3 and Node 14" which SOPHIE does not calculate. This results from generalizing together concepts which are not treated identically in the surface structure. In this case, voltage, current, resistance and power dissipation were generalized to the concept of a measurable quantity. Allowing the grammar to accept more statements and having the argument-checking done by the procedural specialists has the advantage of allowing the semantic routines to provide the feedback as to why a sentence cannot be interpreted or "understood". It also keeps the grammar from being cluttered with special rules for blocking meaningless phrases. Carried to the limit, the generalization strategy would return the grammar to being "syntactic" again (e.g. all data objects are "noun phrases"). The trick is to leave semantics in the grammar when it is beneficial -- to stop extraneous parsings early, or tighten the range of a referent for an ellipsis or deletion. This is obviously a task-specific trade-off.(14)

---

(14) Bobrow and Brown (1975) describe an interesting paradigm from which to consider this trade-off.

The relationship between a phrase and its meaning is usually straightforward. However, it is not limited to simple embedding. Consider the phrases "the base emitter of Q5 shorted" and "the base of Q5 shorted to the emitter". The thing which is "shorted" in both of these phrases is the "base emitter junction of Q5." The rule that recognizes both of these phrases, <PART/FAULT/SPEC>, can handle the first phrase by invoking its constituent concepts of <JUNCTION> (base emitter of Q5) and <FAULT/TYPE> (shorted) and combine their results. In the second phrase, however, it must construct the proper junction from the separate occurrences of the two terminals involved. Figure 4.2 gives the rules used to recognize these two situations. The situations are distinguished by the occurrence of the optional constituent in the second phrase. (As will be discussed later, the rules are procedurally encoded, which provides a natural way of building separate semantic forms for the two cases.) Notice that the parser does some paraphrasing, as the "meaning" of the two phrases is the same.

Figure 4.2
Grammar Rules

```
<PART/FAULT/SPEC> := <FAULTABLE/THING> is <FAULT/TYPE>
                     [to <TRANSISTOR/TERMINAL/TYPE>]

<FAULTABLE/THING> := <JUNCTION> ! <TERMINAL> ! <PART>

<FAULT/TYPE> := open ! shorted

<TRANSISTOR/TERMINAL/TYPE> := base ! emitter ! collector
```

This discussion has been presented as if the concepts were defined *a priori* by the capabilities of the system. Actually, for the system to remain at all habitable, the concepts are discovered in the interplay between the statements that are made in the domain and the capabilities of the system. When a particular English construct is difficult to handle, it is probably an indication that the concept it is trying to express has not been recognized properly by the system. In our example "the base of Q5 is shorted to the emitter", the relationship between the phrase and its meaning is awkward because the present concept of shorting requires a part or a junction. The example is getting at a concept of shorting, in which any two terminals can be shorted together (e.g. "the positive terminal of R9 is shorted to the anode of D6"). This is a viable conceptual view of "shorting", but its implementation requires allowing arbitrary changes in the topology of the circuit which is beyond the efficiency limitations of SOPHIE's simulator. Thus, the system we were working with led us to define the concept in too limited a way.

USE OF SEMANTIC INFORMATION DURING PARSING

Prediction

Having described the notion of a semantic grammar, we will now describe the ways it allows semantic information to be used in the understanding process. One use of semantic grammars is to predict the possible alternatives that must be checked at a given point. Consider, for example, the phrase "the voltage at xxx". After the word "at" is reached in the top-down, left-to-right parse, the grammar rule corresponding to the concept "measurement" can predict very specifically the conceptual nature of "xxx": it must be a phrase that directly or indirectly specifies a location in the circuit. For example, "xxx" could be "the junctions of the current limiting section and the voltage reference source" but cannot be "3 ohms".

Semantic grammars also have the effect of reducing the amount of grammatical ambiguity. In the phrase "the voltage at xxx", the prepositional phrase "at xxx" will be associated with the noun "voltage" without considering any alternative parses that associates it someplace higher in the tree.

Predictive information is also used to aid in the determination of referents for pronouns. If the above phrase were "the voltage at it", the grammar would be able to restrict the class of possible referents to locations. By taking advantage of the available sentence contexts to predict the semantic class of possible referents, the referent determination process is greatly simplified. For example:

(1a) Set the voltage control to .8?
(1b) What is the current thru R9?
(1c) What is it with it set to .9?

In (1c), the grammar is able to recognize that the first "it" refers to a measurement that the student would like re-taken under slightly different conditions. The grammar can also decide that the second "it" refers to either a potentiometer or to the load resistance (i.e. one of those things which can be set). The referent for the first "it" is the measurement taken in (1b), "the current thru R9". The referent for the second "it" is "the voltage control" which is an instance of a potentiometer. The context mechanism that selects the referents will be discussed later.

Simple Deletion

The semantic grammar is also used to recognize simple deletions. The grammar rule for each conceptual entity knows the nature of that entity's constituent concepts. When a rule cannot find a constituent concept, it can either:

a) fail (if the missing concept is considered to be obligatory in the surface structure representation) or,

b) hypothesize that a deletion has occurred and continue.

For example, the concept of a TERMINAL has as one of its realizations the constituent concepts of a TERMINAL-TYPE and a PART. When its grammar rule finds only the phrase "the collector", it uses this information to posit that a part has been deleted (i.e. TERMINAL-TYPE gets instantiated to "the collector" but nothing gets instantiated to PART). The natural language processor then uses the dependencies between the constituent concepts to determine that the deleted PART must be a TRANSISTOR. The "meaning" of this phrase is then "the collector of some transistor". Which transistor is determined when the meaning is evaluated in the present dialogue context. In particular, the semantic form returned is the function PREF and the classes of possible referents; in our example the form would be (COLLECTOR (PREF '(TRANSISTOR))).(15) The operation of PREF will be discussed later.

Ellipsis

Another use of the semantic grammar allows the processor to recognize elliptic utterances. These are utterances that do not express complete thoughts -- a completely specified question or command -- but only give differences between the intended thought and an earlier one.(16) For example, 2b, 2c and 2d are elliptic utterances.

---

(15) The language LISP will be used in examples throughout this thesis. In LISP, a function call is expressed in Cambridge-Polish notation: as a parenthesized list of the function name followed by its arguments.

(2a) What is the voltage at Node 5?
(2b) At Node 1?
(2c) and Node 2?
(2d) What about between nodes 7 and 8?

Ellipses can begin with introductory phrases such as "and" in 2c or "what about" in 2d; however this is not required as can be seen in 2b. Part of the ellipsis rule is given in Figure 4.3.

Figure 4.3

Ellipsis Rule

```
<ELLIPSIS> := [<ELLIPSIS/INTRODUCER>] <REQUEST/PIECE> !
              [<ELLIPSIS/INTRODUCER>] if <PART/FAULT/SPEC>

<REQUEST/PIECE> := [<PREP>] <NODE> !
                   [<PREP>] <PART> !
                   between <NODE> and <NODE> !
                   [<PREP>] <JUNCTION> !
                   etc.
```

The grammar rule identifies which concept or class of concepts are possible from the context available in the elliptic utterance.

While the parser is usually able to determine the intended concepts from the context available in an elliptic utterance, this is not always the case. Consider the following two sequences of statements.

(3a) What is the voltage at Node 5?
(3b) 10?

(4a) What is the output voltage if the load is 100?
(4b) 10?

In (3b), "10" refers to node 10, while in (4b) it refers to a load of 10. The problem this presents to the parser is that the concepts underlying these two elliptic utterances have nothing in common except their surface realizations. The parser, which operates from conceptual entities, does not have a concept that includes both of these interpretations. One solution would be to have the parser find all parses (concepts) and then choose between them on the basis of context. Unfortunately, this would mean that time is wasted looking for more than one parse for the large percentage of sentences in which it is not necessary to do so. A better solution would be to allow structure among the concepts, so that the parser would recognize "10" as a member of the concept "number". Then the routines that find the referent would know that numbers can be either node numbers or values. This type of recognition could profitably be performed by a bottom-up approach to parsing. However, its advantages over the present scheme are not enough to justify the expense incurred by a bottom-up parse to find all possible well-formed constituents. At present, the parser assumes one interpretation, and a message is printed to the student indicating the assumed interpretation. If it is wrong, the student must supply more context in his request. In fact, "10?" is taken as a load specification and if the student meant the node he would have to use "at 10", "N10" or "Node 10". Later we will discuss the mechanism that determines to which complete thought an ellipsis refers.

---

(16) The standard use of the word "ellipsis" refers to any deletion. Rather than invent a new word, we shall use the restricted meaning here.

USING CONTEXT TO DETERMINE REFERENTS

Pronouns and Deletions

Once the parser has determined the existence and class (or set of classes) of a pronoun or deleted object, the context mechanism is invoked to determine the proper referent. This mechanism has a history of student interactions during the current session which contains, for each interaction, the parse (meaning) of the student's statement and the response calculated by the system. This list provides the range of possible referents and is searched in reverse order to find an object of the proper semantic class (or one of the proper classes). To aid in the search, the context mechanism knows how each of the procedural specialists appearing in a parse uses its arguments. For example, the specialist MEASURE has a first argument that must be a quantity and a second argument that must be a part, a junction, a section, a terminal or a node. Thus when the context mechanism is looking for a referent that can either be a PART or a JUNCTION, it will look at the second argument of a call to MEASURE but not the first. Using the information about the specialists, the context mechanism looks in the present parse and then in the next most recent parse, etc. until an object from one of the specified classes is found.

The significance of using the specialist to filter the search instead of just keeping a list of previously mentioned objects is that it avoids mis-interpretations due to object-concept ambiguity. As an example, consider the following sequence from the sample dialogue in Chapter 3:

(5) What is the current thru the CC when the VC is 1.0?
(6) What is it when it is .8?

Sentence (5) will be recognized by the following rules from the semantic grammar:

```
$1) <REQUEST> := <SIMPLE/REQUEST> when <SETTING/CHANGE>
$2) <SIMPLE/REQUEST> := what is <MEASUREMENT>
$3) <MEASUREMENT> := <MEAS/QUANT> <PREP> <PART>
$4) <SETTING/CHANGE> := <CONTROL> is <CONTROL/VALUE>
$5) <CONTROL> := VC
```

with a resulting semantic form of:

```
(RESETCONTROL (STQ VC 1.0)
              (MEASURE CURRENT CC))
```

RESETCONTROL is a function whose first argument specifies a change to one of the controls and whose second argument consists of a form to be evaluated in the resulting instrument context. STQ is used to change the setting of the one of the controls. The first argument to MEASURE gives the quantity to be measured. The second specifies where it is to be measured. To recognize sentence (6), the application of rules $2 and $5 are changed. There is an alternative rule for <SIMPLE/REQUEST> that looks for those anaphora that refer to a measurement. These phrases, such as "it", "that result" or "the value", are recognized by the non-terminal <MEASUREMENT/PRONOUN>. The alternative to $2 that would be used to parse (6) is:

```
<SIMPLE/REQUEST> := what is <MEASUREMENT/PRONOUN>
```

The semantics of <MEASUREMENT/PRONOUN> indicate that an entire measurement has been deleted. The alternative to rule $5:

```
<CONTROL> := it
```

recognizes "it" as an acceptable way to specify a control. The resulting semantic form for sentence (6) is:

```
(RESETCONTROL (STQ (PREF '(CONTROL)) .8)
              (PREF '(MEASUREMENT)))
```

The function PREF searches back through the context of previous semantic forms to find the most recent mention of a member one of the classes. In the above example, it will find the control VC but not CC because the character imposed on the arguments of MEASURE is that of a "part" not a "control".(17) The presently recognized classes for deletions are PART, TRANSISTOR, FAULT, CONTROL, POT, SWITCH, DIODE, MEASUREMENT and QUANTITY. (The members of the classes are derived from the semantic network associated with a circuit.)

Referents for Ellipses

If the problem of pronoun resolution is looked upon as finding a previously mentioned object for a currently specified use, then the problem of ellipsis can be thought of as finding a previously mentioned use for a currently specified object. For example:

(7) What is the base current of Q4?
(8) In Q5?

The given object is "Q5", and the earlier function is "base current". For a given elliptic phrase, the semantic grammar identifies the concept (or class of concepts) involved. In (7), since Q5 is recognized by the non-terminal <TRANSISTOR/SPEC>, the class would be TRANSISTOR. The context mechanism then searches for a specialist in a previous parse that accepted the given class as an argument. When one is found, the new phrase is placed in the proper argument position and the modified parse is used as the meaning of the ellipsis.

Limitations to the Context Mechanism

The method of semantic classification (to determine reference) is very efficient and works well over our domain. It definitely does not solve all the problems of reference. Charniak has pointed out the substantial problems of reference in a domain as seemingly simple as children's stories (1972). One of his examples demonstrates how much world knowledge may be required to determine a referent (1972 p. 7).

---

(17) The character imposition as described is too strong. For example:
$1) What are the specs of Q5?
$2) What is the voltage at its emitter?
The character imposed on Q5 in $1 is that of a part which means that the context mechanism invoked by $2 which is looking for a transistor won't find it. This example is handled by relaxing the restrictions the procedural specialist in $1 puts on its argument (i.e. it can be either a PART or a TRANSISTOR). In spite of this weakness in the argument limitation approach, we have found it to be a useful means of reducing the search time and avoiding some obvious mis-interpretations.

> Janet and Penny went to the store to get presents for Jack. Janet said "I will get Jack a top" "Don't get Jack a top" said Penny. "He has a top. He will make you take it back."

Charniak argues that to understand to which of the two tops "it" refers, requires knowing about presents, stores and what they will take back, etc. Even in domains where it may be possible to capture all of the necessary knowledge, classification may still lead to ambiguities. For example, consider the following:

(9) What is the voltage at Node 5 if the load is 100?
(10) Node 6?
(11) 7?

In statement (11) the user means Node 7. In statement (10), he has reinforced the use of ellipsis as referring to node number. (For example, leaving out statment (10), sentence (11) is much more awkward.) On the other hand, if statement (11) had been "1000" or if statement (10) had been "10?", things would be more problematic. When statement (11) is "1000", we can infer that he means a load of 1000 because there is no node 1000. If statement (10) had been "10?", there would be genuine ambiguity slightly favoring the interpretation as a load because that was the last number mentioned. The major limitation of the current technique, which must be overcome in order to tackle significantly more complicated domains, is its inability to return more than one possible referent. It considers each one individually until it finds one which is satisfactory. The amount of work involved in employing a technique which allows comparing referents has not been justified by our experience.

RELATIONSHIP TO OTHER SEMANTIC SYSTEMS

The relationship between semantic grammars and purely semantic systems (Quillian 1969; Schank et al. 1975) and to some extent Wilks (1973a, 1973b) parallels the distinction between procedural and declarative knowledge. The relationship that exists between nodes in the semantic network structure contains little or no information about how these relationships might be expressed in language. An interpretation mechanism must decide where the information is useful. While this is, in some sense, more general (the same information can be used for several purposes given the proper interpreter), it is necessarily less efficient. (Wilks has extracted some expressive information, primarily concept order, into his templates.) A semantic grammar, on the other hand, is written for the process of recognizing concepts as they are expressed in the surface structures.

FUZZINESS

Having the grammar centered around semantic categories allows the parser to be sloppy about the actual words it finds in the statement. Having a concept in mind, and being willing to ignore words to find it, is the essence of keyword parsing schemes. It is effective in those cases where the words that have been skipped are either redundant, or specify gradations of an idea that are not distinguished by the system. For example, in the sentence: "Insert a very hard fault", "very" would be ignored; this is effective because the system does not have any further structure over the class of hard faults. In the sentence: "What is the voltage across resistor R8?" resistor can be ignored because it is implied by "R8".(18)

One advantage that a procedural encoding of the grammar (discussed later) has over pattern matching schemes in the implementation of fuzziness is its ability to control exactly where words can be ignored. This provides the ability to blend pattern matching parsing of those concepts that are amenable to it with the structural parsing required by more complex concepts. The amount of fuzziness -- how many, if any, words in a row can be ignored -- is controlled in two ways. First, whenever a grammar rule is invoked, the calling rule has the option of limiting the number of words that can be skipped. Second, each rule can decide which of its constituent pieces or words are required and how tightly controlled the search for them should be. In SOPHIE, the normal mode of operation of the parser is tight in the beginning of a sentence, but fuzzier after it has made sense out of something.

---

(18) The first of these examples could be handled by making "very" a noise word (i.e. deleting it from all sentences). Resistor however is not a noise word in all cases (e.g. "What is the current through the current sensing resistor?") and hence cannot be deleted.

Fuzziness has two other advantages worth mentioning briefly. It reduces the size of the dictionary because all known noise words don't have to be included. In those cases where the skipped words are meaningful, the misunderstanding may provide some clues to the user which allow him to restate his query.

PREPROCESSING

Before a statement is parsed, a preprocessor performs three operations. The first expands abbreviations, deletes known noise words, and canonicalizes similar words to a common form. The second is a cursory spelling correction. The third is a reduction of compound words.

Spelling correction is attempted on any word of the input string that the system does not recognize. The spelling correction algorithm(19) takes the possibly misspelled word, and a list of correctly spelled words, and determines which, if any, of the correct words is close to the misspelled word (using a metric determined by number of transpositions, doubled letters, dropped letters, etc.). During the initial preprocessing, the list of correct words is very small (approximately a dozen) and is limited to very commonly misspelled words and/or words that are critical to the understanding of a sentence. The list is kept small so that the time spent attempting spelling correction, prior to attempting a parse, is kept to a minimum. Remember that the parser has the ability to ignore words in the input string so we do not want to spend a lot of time correcting a word that won't be needed in understanding the statement. But notice that certain words can be critical to the correct understanding of a statement. For example, suppose that the phrase "the base emitter current of Q3" was incorrectly typed as "the bse emitter current of Q3". If "bse" were not recognized as being "base" the parser would ignore it and (mis-)understand the phrase as "the emitter current of Q3", a perfectly acceptable but much different concept.(20) Because of this problem, words like "base", which if ignored have been found to lead to misunderstandings, are considered critical and their spelling is corrected before any parse is attempted.

---

(19) The spelling correction routines are provided by INTERLISP and were developed by Teitelman for use in the DWIM facility (Teitelman 1969,1974).
(20) To minimize the consequences of such misinterpretation, the system always responds with an answer that indicates what question it is answering, rather than just giving the numeric answer.

Note that there are a lot of words -- "capacitor", "replace", "open", for example -- that if misspelled would prevent the parser from making sense of the statement, but would not lead to any mis-understandings. These words therefore are not considered to be critical, and would be corrected in the second attempt at spelling correction that is done after a statement fails to parse.

Compound words are single concepts that appear in the surface structure as a fixed series of more than one word. Their reduction is very important to the efficient operation of the parser. For example, in the question "what is the voltage range switch setting?", "voltage range switch" is rewritten as the single item "VR". If not rewritten, "voltage" would be mistaken as the beginning of a measurement (as in "what is the voltage at N4") and an attempt would have to be made to parse "range switch setting" as a place to measure voltage. Of course after this failed, the correct parse can still be found, but reducing compound words helps to avoid backtracking. In addition, the reduction of compound words simplifies the grammar rules by allowing them to work with larger conceptual units. In this sense, the preprocessing can be viewed as a preliminary bottom-up parse that recognizes local, multi-word concepts.

IMPLEMENTATION

Once the dependencies between semantic concepts have been expressed in the BNF form, each rule in the grammar is encoded (by hand) as a LISP procedure. This encoding process imparts to the grammar a top-down control structure, specifies the order of application of the various alternatives of each rule, and defines the process of pattern matching each rule. The resulting collection of LISP functions constitutes a goal-oriented parser in a fashion similar to SHRDLU (Winograd 1973), but without the backtracking ability of PROGRAMMAR.

As has been argued elsewhere (Woods 1970; Winograd 1973), encoding the grammars as procedures -- including the notion of process in the grammar -- has advantages over using traditional phrase structure grammar representations. Four of these advantages are:

1) the ability to collapse common parts of a grammar rule while still maintaining the perspicuity of the grammar.

2) the ability to collapse similar rules by passing arguments (as with SENDR).

3) the ease of interfacing other types of knowledge (in SOPHIE, primarily the semantic network) into the parsing process.

4) the ability to build and save arbitrary structures during the parsing process.(21)

In addition to the advantages it shares with other procedural representations, the LISP encoding has the computational advantage of being compilable directly into efficient machine code. The LISP implementation is efficient because the notion of process it contains (one process doing recursive descent) is close to that supported by physical machines, while those of ATN and PROGRAMMAR are non-deterministic and hence not directly translatable into present architecture. See (Burton 1976) for a description of how it is possible to minimize this mismatch.) Appendix B describes the details of the LISP implementation and provides an example of a rule from the grammar.

In terms of efficiency, the LISP implementation of the semantic grammar succeeds admirably. The grammar written in INTERLISP (Teitelman 1974) can be block compiled. Using this technique, the complete parser takes about 5K of storage and parses a typical student statement consisting of 8 to 12 words in around 150 milliseconds! Appendix C presents parses and timings of some of the sentences used in the dialogue.

---

(21) This ability is sometimes provided by allowing augments on phrase structure rules.

Chapter 5

A NEW FORMALISM -- SEMANTIC AUGMENTED TRANSITION NETWORKS

Using the techniques described in Chapter 4, a natural language front-end, capable of supporting the dialogue presented in Chapter 3, and requiring less than 200 milliseconds cpu time per question, was constructed. In addition, these same techniques were used to build a front-end for NLS-SCHOLAR (Grignetti et al. 1974; Grignetti et al. 1975) (built by C. Hausmann), and an interface to an experimental laboratory for exploring mathematics using attribute blocks (Brown et al. 1976). In the construction of these varying systems, the notion of semantic grammar proved to be useful. The LISP implementation, however, was found to be a bit unwieldy. While expressing the grammar as programs has benefits in the area of efficiency and allows complete freedom to explore new extensions, the technique is lacking in perspicuity. This lack of perspicuity has three major drawbacks: (1) the difficulty encountered when trying to modify or extend the grammar; (2) the problem of trying to communicate the extent of the grammar to either a user or a colleague; (3) the problem of trying to re-implement the grammar on a machine that does not support LISP. These difficulties have been partially overcome by using a second, parallel representation of the grammar in a BNF-like specification language which is the representation we have been presenting throughout this report. This, however, requires supporting two different representations of the same information and does not really solve problems (1) or (3). The solution to this problem is a better formalism for expressing and thinking about semantic grammars.

Augmented Transition Networks (ATN)

Some years ago, Chomsky (1957) introduced the notion that the processes of language generation and language recognition could be viewed in terms of a machine. One of the simplest of such models is the finite state machine. It starts off in its initial state looking at the first symbol, or word, of its input sentence and then moves from state to state as it gobbles up the remaining input symbols. The sentence is accepted if the machine stops in one of its final states after having processed the entire input string; otherwise the sentence is rejected. A convenient way of representing a finite state machine is as a transition graph, in which the states correspond to the nodes of the graph and the transitions between states correspond to its arcs. Each arc is labelled with a symbol whose appearance in the input can cause the given transition.

In an augmented transition network, the notion of a transition graph has been modified in three ways: (1) the addition of a recursion mechanism that allows the labels on the arcs to be non-terminal symbols that correspond to networks; (2) the addition of arbitrary conditions on the arcs that must be satisfied in order for an arc to be followed; (3) the inclusion of a set of structure building actions on the arcs, together with a set of registers for holding partially built structures.(22) Figure 5.1 is a specification of a language for representing augmented transition networks. The specification is given in the form of an extended, context-free grammar in which alternative ways of forming a constituent are represented on separate lines and the symbol "+" is used to indicate arbitrarily repeatable constituents.(23) The non-terminal symbols are lower case English descriptions enclosed in angle brackets. All other symbols, except "+", are terminals. Non-terminals not given in Figure 5.1 have names that should be self-explanatory.

Figure 5.1
A Language for Representing ATNs

```
<transition network> := (<arc set> <arc set>+)
<arc set> := (<state> <arc>+)
<arc> := (CAT <category name> <test> <action>+ <term act>)
         (WRD <word> <test> <action>+ <term act>)
         (PUSH <state> <test> <action>+ <term act>)
         (TST <arbitrary label> <test> <action>+ <term act>)
         (POP <form> <test>)
         (VIR <constituent name> <test> <action>+ <term act>)
         (JUMP <state> <test> <action>+)
<action> := (SETR <register> <form>)
            (SENDR <register> <form>)
            (LIFTR <register> <form>)
            (HOLD <constituent name> <form>)
            (SETF <feature> <form>)
<term act> := (TO <state>)
```

---

(22) This discussion follows closely a similar discussion in Woods (1970) to which the reader is referred. If the reader is familiar with the ATN formalism he/she may wish to skip to the section "Advantages to the ATN Formalism".

(23) "+" is used to mean 0 or more occurrences. While the accepted usage of "+" is 1 or more, the accepted symbol for 0 or more, "*", has not been used to avoid confusion with the use of the symbol * in the ATN formalism.

```
<form> := (GETR <register>)
          LEX
          *
          (GETF <form> <feature>)
          (BUILDQ <fragment> <register>+)
          (LIST <form>+)
          (APPEND <form> <form>)
          (QUOTE <arbitrary structure>)
```

The first element of each arc is a word indicating the type of arc. For CAT, WRD and PUSH arcs, the arc type together with the second element correspond to the label on an arc of a state transition graph. The third element is an additional test. A CAT arc can be followed, if the current input symbol is a member of the lexical category named on the arc, and if the test on the arc is satisfied. A PUSH arc causes a recursive invocation of a lower level network beginning at the state indicated, if the test is satisfied. The WRD arc can be followed if the current input symbol is the word named on the arc and if the test is satisfied. The TST arc can be followed if the test is satisfied (the label is ignored). The VIR arc (virtual arc) can be followed if a constituent of the named type has been placed on the hold list by a previous HOLD action and the constituent satisfies the test. In all of these arcs, the actions are structure building actions, and the terminal action specifies the state to which control is passed as a result of the transition. After CAT, WRD and TST arcs, the input is advanced; after VIR and PUSH arcs it is not. The JUMP arc can be followed whenever its test is satisfied, control being passed to the state specified in the second element of the arc without advancing the input. The POP arc indicates the conditions under which the state is to be considered a final state and the form of the constituent to be returned.

The actions, forms and tests on an arc may be arbitrary functions of the register contents. Figure 5.1 presents a useful set that illustrates major features of the ATN. The first three actions specified in Figure 5.1 cause the contents of the indicated register to be set to the value of the indicated form. SETR causes this to be done at the current level of computation, SENDR at the next lower level of embedding, so that information can be sent down during a PUSH, and LIFTR at the next higher level of computation, so that additional information can be returned to higher levels. The HOLD action places a form on the HOLD list to be used at a later place in the computation by a VIR arc. SETF provides a means of setting a feature of the constituent being built.

GETR is a function whose value is the contents of the named register. LEX is a form whose value is the current input symbol. The asterisk (*) is a form whose value depends on the context of its use: (1) in the actions of a CAT arc, the value of * is the root form of the current input word; (2) in the actions of a PUSH arc, it is the value of the lower computation; and (3) in the actions following a VIR arc, the value of it is the constituent removed from the HOLD list. GETF is a function which determines the value of a specified feature of the indicated form (which is usually *). BUILDQ is a general structure-building form that places the values of the given registers into a specified tree fragment. Specifically, it replaces each occurrence of + in the tree fragment with the contents of one of the registers (the first register replacing the first occurrence of +, the second register the second, etc.). In addition, BUILDQ replaces occurrences of * by the value of the form *. The remaining three forms make a list out of the specified arguments (LIST), append two lists together to make a single list (APPEND) and produce as a value the (unevaluated) argument form (QUOTE).

Advantages of ATN Formalism

The ATN formalism was seriously considered at the beginning of the SOPHIE project, but rejected as being too slow. In the course of developing the LISP grammar, it became clear that the primary reason for a significant difference in speed between an ATN grammar and a LISP grammar is due to the fact that processing the ATN is an interpreted process, whereas LISP is compilable and therefore the time problem could be overcome by building an ATN compiler. During the period of evolution of SOPHIE's grammar, an ATN compiler was constructed (see Burton 1976). In the next section we will discuss the advantages we hoped to gain by using the ATN formalism.

These advantages fall into three general areas: (1) conciseness, (2) conceptual effectiveness and (3) available facilities. By conciseness we mean that writing a grammar as an ATN takes less characters than LISP. The ATN formalism gains conciseness by not requiring the specification of details in the parsing process at the same level required in LISP. Most of these differences stem from the fact that the ATN assumes it has a machine whose operations are designed for parsing, while LISP assumes it has a lambda calculus machine. For example, a lambda calculus machine assumes a function has one value. A function call to look for an occurrence at a non-terminal while parsing (in ATN formalism, a PUSH) must return at least two values: the structure of the constituent found, and the place in the input where the parsing stopped. A good deal of complexity is added to the LISP rules in order to maintain the free variable which has to be introduced to return the structure of the constituent. Other examples of unnecessary details include the binding of local variables and the specification of control structure as ANDs, ORs and CONDs.

The conciseness of the ATN results in a grammar that is easier to change, easier to write and debug, easier to understand, and hence to communicate. We realize that conciseness does not necessarily lead to these results (APL being a prime example in computer languages mathematics in general being another), however, this is not a problem. The correspondence between the grammar rules in LISP and ATN is very close. The concepts which were expressed as LISP code can be expressed in nearly the same way as ATNs but in fewer symbols.

The second area of improvement deals with conceptual effectiveness. Loosely defined, conceptual effectiveness is the degree to which a language encourages one to think about problems in the right way. One example of conceptual effectiveness can be seen by considering the implementation of case structured rules.(24) In a typical case structure rule, the verb expresses the function (or relation name) and the subject, while the object and prepositional phrases express the arguments of the function or relation. Let us assume for the purpose of this discussion that we are looking at four different cases (agent, location, means, and time) of the verb GO -- John went to the store by car at 10 o'clock. In a phrase structure rule-oriented formalism one would be encouraged to write:

<statement> := <actor> <action/verb> <location> <means> <time>

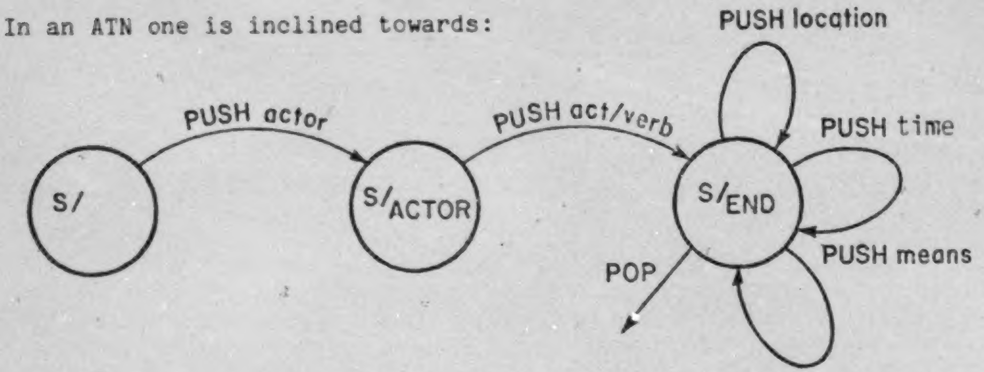
Since the last three cases can appear in any order, one must also write 5 other rules:

---

(24) See Bruce (1975) for a discussion of case systems.

```
<statement> := <actor> <action/verb> <location> <time> <means>
  .
  .
  .
```

In an ATN one is inclined towards:



which expresses more clearly the case structure of the rule. There is no reason why in the LISP version of the grammar one couldn't write loops that are exactly analogous to the ATN (the ATN compiler, after all, produces such code!). However, a rule-oriented formalism does not encourage one to think this way. An alternative rule implementation is:

```
<action>:= <actor><action/verb><action1>
<action1>:= <action1><temporal>
<action1>:= <action1><location>
<action1>:= <action1><means>
```

this is easier (shorter) to write but it has the disadvantage of being left-recursive. To implement it, one is forced to write the LISP equivalent of the ATN that creates a difference between the rule representation and the actual implementation. This method also has the disadvantage of introducing an unmotivated non-terminal.

Another conceptual advantage of the ATN framework is that it encourages the postponing of decisions about a sentence until a differential point is reached, thereby allowing potentially different paths to stay together. In the rule oriented SOPHIE grammar there are top level rules for <set>, a command to change one of the control settings and <modify>, a command to fault the instrument in some way. Sentence (1) is a <set> and sentence (2) is a <modify>.

(1) Suppose the current control is high.
(2) Suppose the current control is shorted.

The two parse paths for these sentences should be the same for the first five words, but they are separated immediately by the rules <set> and <modify>.(25) An ATN encourages structuring the grammar so that the decision between <set> and <modify> is postponed so that the paths remain together. It could be argued that the fact that this example occurred in SOPHIE's grammar is a complaint against top-down parsing or semantic grammars, or just our particular instantiation of a semantic grammar. We suspect the latter but argue that rule representations encourages this type of behavior.

Another conceptual aid provided by ATNs is their method of handling ambiguity. Our LISP implementation uses a recursive descent technique (which can alternatively be viewed as allowing only one process). This requires that any decision between two choices be made correctly because there is no way to try out the other choice *after* the decision is made. At choice points, a rule can, of course, "look ahead" and gain information on which to base the decision, similar to the "wait-and-see" strategy used by Marcus (1975) but there is no way to back up and remake a decision once it has returned.

The effects of this can be most easily seen by considering the lexical aspects of the parsing. A prepass collapses compound words, expands abbreviations, etc. This allows the grammar to be much simpler because it can look for units like "voltage/control" instead of having to decode the noun phrase "voltage control". Unfortunately without the ability to handle ambiguity, this rewriting can only be done on words that have no other possible meaning. So, for example, when the grammar is extended to handle:

(3) Does the voltage control the current limiting section?

the compound "voltage/control" would have to be removed from the prepass rules and included in the grammar. This reduces the amount of bottom-up processing that can be done and results in a slower parse. It also makes compound rules difficult to write because all possible uses of the individual words must be considered to avoid errors. Another example is the use of the letter "C" as an abbreviation. Depending on context, it could possibly mean either current, collector or capacitor. Without allowing ambiguity in the input, it could not be allowed as an abbreviation unless explicitly recognized by the grammar.

---

(25) The degree to which the separation of paths is a problem can be greatly reduced using a preprocessing "compilation" state such as Klovstad, which (among other things) collapses rules with the same initial parts. In our example, however this may not work since the phrase "the current control" may be parsed as the non-terminal <CONTROL> in (1) and as the non-terminal <PART> in (2). Of course this would be a poor choice of grammar rules, and no one aware of sentences (1) and (2) would handle it this way. The problem is recognizing where situations such as this occur.

The third general area in which ATNs have an advantage is in the available facilities to deal with complex linguistic phenomena. While our grammar has not yet expanded to the point of requiring any of the facilities, the availability of such facilities cannot be ignored as an argument favoring one approach over another. A primary example is the general mechanism for dealing with coordination in English described in Woods (1973a).

Conversion to Semantic ATN

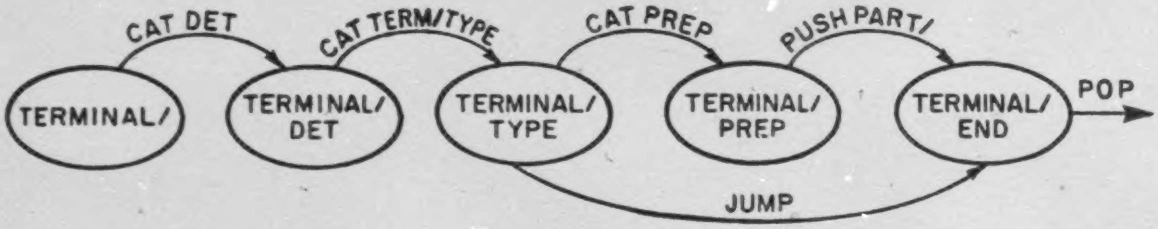
For the reasons discussed above, the SOPHIE semantic grammar was re-written in the ATN formalism. We wish to stress here that the re-writing was a process of changing form only. The content of the grammar remained the same. Since a large part of the knowledge encoded by the grammar continues to be semantic in nature, we call the resulting grammar a "semantic ATN". Figure 5.1 presents the graphic ATN representation of a semantic grammar non-terminal. This is the same rule presented in Figure 4.1, which recognizes the phrases for specifying measurements in a circuit. The actions and structure building operations on the arcs (which are not shown in Figure 5.1) save the recognized constituents and construct the proper interpretation when sufficient information has been collected. Appendix E provides more examples of the semantic ATN used in SOPHIE.

Figure 5.2 presents a simple example of how the recognition of anaphoric deletions can be captured in ATN formalism. The network in Figure 5.2 encodes the straightforward way of expressing a terminal of a part in the circuit -- the base of Q5, the anode of it, the collector. By the state TERMINAL/TYPE, both the determiner and the terminal type -- base, anode have been found. The first arc that leaves TERMINAL/TYPE accepts the preposition that begins the specification of the part. The second arc

(JUMP arc) corresponds to hypothesizing that the specification of the part has been deleted, as in: "The base is open." The action on the arc builds a place-holding form which identifies the deletion and specifies (from information associated with the terminal type which was found) the classes of objects that can fill the deletion. The method for determining the referent of the deletion remains the same as described in Chapter 4.

Figure 5.2

An ATN which recognizes deletion



The SOPHIE semantic ATN is then compiled using the general ATN compiling system described in Burton (1976). The SOPHIE grammar provides the compiling system with a good contrast to the LUNAR grammar, since it does not use many of the potential features. In addition, a bench mark, of sorts, was available from the LISP implementation of the grammar that could be used to determine the computational cost of using the ATN formalism.

There were two modifications made to the compiling system to improve its efficiency for the SOPHIE application. In the SOPHIE grammar, a large number of the arcs check for the occurrence of particular words. When there is more than one arc leaving a state, the ATN formalism requires that all of these arcs be tried, even if more than one of these is a WRD arc and an earlier WRD arc has succeeded. This is especially costly, since the taking of an arc requires the creation of a configuration to try the remaining arcs. In those cases when it is known that none of the other arcs can succeed, this should be avoided. As a solution to this problem, the GROUP arc type was added. The GROUP arc allows a set of contiguous arcs to be designated as mutually exclusive. The form of the GROUP arc is: (GROUP arc1 arc2 ... arcn). The arcs are tried, one at a time, until the conditions on one of the arcs are met. This arc is then taken, and the remaining arcs in the GROUP are forgotten -- not tried. If a PUSH arc is included in the GROUP, it will be taken if its test is true and the remaining arcs will not be tried even if the PUSHed for constituent is not found. For example, consider the following grammar state:

```
(S/1
   (GROUP (CAT A T (TO S/2))
          (WRD X T (TO S/3))
          (CAT B T (TO S/4))))
```

At most, one of the three arcs will be followed. Without GROUPing them together, it is possible that all three might be followed -- if the word X had interpretations as both category A and category B.

The GROUP arc also provides an efficient means of encoding optional constituents. The normal method of allowing options in ATN is to provide an arc that accepts the optional constituent and a second arc that jumps to the next state without accepting anything. For example, if in state s/2 the word "very" is optional, the following two arcs would be created:

```
(S/2
   (WRD  VERY T (TO REST-OF-S/2))
   (JUMP REST-OF-S/2  T))
```

The inefficiency arises when the word "very" does occur. The first arc is taken, but an alternative configuration that will try the second arc must be created, and possibly later explored. By embedding these arcs in a GROUP, the alternative will not be created thus saving time and space. As a result, it won't have to be explored, possibly saving more time. A warning should be included here, that the GROUP arc can reject sentences that might otherwise be accepted. In our example, "very" may be needed to get out of the state REST-OF-S/2. In this respect, the GROUP arc is a departure from the original ATN philosophy that arcs should be independent, and for this we apologize. However, for some applications, the increased efficiency can be critical.

The other change to the compiling system (for the semantic grammar application) dealt with the preprocessing operations. The preprocessing facilities described in the last chapter included: 1) lexical analysis to extract word endings; 2) a substitution mechanism to expand abbreviations; delete noise words, and canonicalize synonyms; 3) dictionary retrieval routines; and 4) a compound word mechanism to collapse multi-word phrases. For the SOPHIE application we added the ability to use the INTERLISP spelling correction routines and the ability to derive word definitions from SOPHIE's semantic net. The extraction of definitions from the semantic network for part names and node names reduces the size of the dictionary and simplifies the operations of changing circuits. In addition, a mechanism called MULTIPLES was developed that permits string substitution within the input. This is similar to the notion of compounding, but differs in that a compound rule creates an alternative lexical item while the multiple rule creates a different lexical item. After the application of a compound rule, there is an additional edge in the input chart; after a multiple rule, the effect is the same as if the user had typed in a different string.

Fuzziness

The one aspect of the LISP implementation that has not been incorporated into the ATN framework is fuzziness, the ability to ignore words in the input. While we have not worked out the details, the non-determinism provided by ATNs lends itself to an interesting approach. In a one-process -- recursive descent -- implementation, the rule that checks for a word must decide (with information passed down from higher rules) whether to try skipping a word, or give up. The critical information that is not available when this decision has to be made is whether or not there is another parse that would use that word. In the ATN, it is possible to suspend a parse and come back to it after all other paths have been tried. Fuzziness could be implemented so that rather than skip a word and continue, it can skip a word and suspend, waiting for the other parses to fail or suspend. The end effect may well be that sentences are allowed to get fuzzier because there is no danger of missing the correct parse.

Comparison of Results

The original motivation for changing to the ATN was its perspicuity. Appendices A and B show the BNF/LISP version, which can be compared with Appendix E, that shows the ATN version. We suspect that the reader will find that neither of them are particularly readable, but then there is no reason to expect that this should be the case. As Winograd (1973) has pointed out, simple grammars are perspicuous in almost any formalism; complex grammars are still complex in any formalism. We found the ATN formalism much easier to think in, write in, and debug. The examples of redundant processing that were presented earlier in this chapter were discovered while converting to ATN. For a gross comparison on conciseness, the ATN grammar requires 70% less characters to express than the LISP version.

The efficiency results were surprising. Table 5.1 gives comparison timings between the LISP version and the ATN compiled version. As can be seen, the ATN version is more than twice as fast. This was pleasantly counter-intuitive, as we expected the LISP version to be much faster due to the amount of hand optimization that had been done while encoding the grammar rules. In presenting the comparison timing, it should be mentioned that there are three differences between the two systems that tended to favor the ATN version.(26) One difference was the lack of fuzziness in the ATN version. The LISP version spent time testing words other than the current word, looking ahead to see if it were possible to skip this word, which was not done in the ATN version. The second is the creation of categories for words during the preprocessing in the ATN version that reduced the amount of time spent accessing the semantic net and hence reduced the time required to perform a category membership test in the ATN system. The third was the simplification of the grammar and increase in the amount of bottom-up processing that could be done because of the ambiguity allowed in the input chart. In our estimation, the lack of fuzziness is the only difference that may have had a significant effect, and this can be included explicitly in the ATN in places where it is critical, by using TST arcs and suspend actions, without a noticeable increase in processing time. In conclusion, we are very pleased with the results of the compiled semantic ATN and feel that the ATN compiler makes the ATN formalism computationally efficient enough to be used in real systems.

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(26) The exact extent to which each of these differences contributed is difficult to gather statistics on due to the block compiler which gains efficiency by hiding internal workings. The exact contribution of each could certainly be determined but was not deemed worth the effort.

Table 5.1

Comparison of ATN vs LISP Implementation

Times (in seconds) are "prepass" + "parsing"

1) What is the output voltage?

LISP - .024 + .018 = .042
ATN - .048 + .033 = .081

2) What is the voltage between there and the base of Q6?

LISP - .038 + .039 = .077
ATN - .090 + .046 = .136

3) Q5?

LISP - .010 + .046 = .056
ATN - .013 + .060 = .073

4) What is the output voltage when the voltage control is set to .5?

LISP - .045 + .038 = .083
ATN - .096 + .048 = .144

5) If Q6 has an open emitter and a shorted base collector junction what happens to the voltage between its base and the junction of the voltage limiting section and the voltage reference source?

LISP - .206 + .188 = .394
ATN - .259 + .090 = .349

Chapter 6

OBSERVATIONS ON STUDENT USAGE

When we began developing a natural language processor for an instructional environment, we knew it had to be (1) fast, (2) habitable, and (3) self-teaching. The basic conclusion that has arisen from the work presented here is that it is possible to satisfy these constraints. The notion of semantic grammar (presented in Chapter 4) provides a paradigm for organizing the knowledge required in the understanding process that permits efficient parsing. In addition, semantic grammar aids the habitability by providing insights into a useful class of dialogue constructs, and permits efficient handling of such phenomena as pronominalizations and ellipses. The need for a better formalism for expressing semantic grammars led to the use of Augmented Transition Networks (presented in Chapter 5). The ability of the ATN-expressed semantic grammar to satisfy the above stated requirements is demonstrated in the natural language front-end for the SOPHIE system.

A point that needs to be stressed is that the SOPHIE system has been (and is being) used by uninitiated students in experiments to determine the pedagogical effectiveness of its environments. While much has been learned about the problems of using a natural language interface, these experiments were not "debugging" sessions for the natural language component. The natural language component has unquestionably reached a state at which it can be conveniently used to facilitate learning about electronics. In this chapter, we will describe the experiences of students using the natural language component, and present some ideas on handling erroneous inputs.

Impressions, Experiences and Observations

Prior to any exposure to SOPHIE, a group of four students were asked to write down all of the ways they could think of for requesting the voltage at a particular node. Although the intent of the experiment was to determine the range of paraphrases that students might be inclined to use before they were aware of the system's linguistic limitations, a more interesting result emerged. Each student wrote down one phrasing very quickly but had a difficult time thinking of a second, even though the initial phrasing by three of the students were in fact different! One student quit, exclaiming "But there is only one way to ask that!" This same inability to perform linguistic paraphrase carried over to the actual interaction with SOPHIE via terminal. Whenever the system did not accept a query, there was a marked delay before the student tried again. Sometimes the student would abandon his line of questioning completely. At the same time, data collected over many sessions indicated that there was no standard -- canonical -- way to phrase a question. Table 6.1 provides some examples of the range of phrasings used by students to ask for the voltage at a node.

Table 6.1
Sample Student Inputs

The following are some of the input lines typed by students with the intent of discovering the voltage at a node in the circuit.

What is the voltage at node 1?
What is the voltage at the base of Q5?
How much voltage at N10?
And what is the voltage at N1?
N9?
V at the neg side of C6?
V11 is?
What is the voltage from the base of transistor Q5 to ground?
What V at N16?
Coll. of Q5?
Node 16 Voltage?
What is the voltage at pin 1?
Output?

As Table 6.1 shows, students are likely to conceive of their questions in many ways and to express each of these conceptions in any of several phrasings. Yet other experiences indicate that they lack the ability to easily convert to another conceptualization or phrasing. Since the non-acceptance of questions creates a major interruption in the student's thought process, the acceptance of many different paraphrases is critical to maintaining flow in the student's problem solving.

Another interesting phenomenon that occurred during sessions was the change in the linguistic behavior of the students as they used the system. Initially, queries were stated as complete English questions, generally stated in templates created by the students from the written examples of sessions that we had given them. If they needed to ask something that did not exactly fit one of their templates, they would try a minor variant. As they became more familiar with the mode of interaction, they began to use abbreviations, to leave out parts of their questions and, in general, to assume that the system was following their interaction. After five hours of experience with the system, almost all of one student's queries contained abbreviations and one in six depended on the context established by previous statements.

FEEDBACK - When the Grammar Fails

From our experiences with students using SOPHIE, we have been impressed with the importance of providing feedback to unacceptable inputs -- what to do when the system doesn't understand an input --. While it may appear that in a completely habitable system all inputs would be understood, no system has ever attained this goal and none will in the foreseeable future. To be natural to a naive user, an intelligent system should act intelligently when it fails too. The first step towards having a system fail intelligently is the identification of possible areas of error. In student's use of the SOPHIE system, we have found the following types of errors to be common:

(1) Spelling errors and mis-typings - "Shortt the CE og Q3 and opwn its base"; "What isthe vbe Q5?"

(2) Inadvertent omissions - "What is the BE of Q5?" (The user left out the quantity to measure. Note that in other contexts this is a well formed question.)

(3) Slight misconceptions that are predictable - "What is the output of transistor Q3?" (The output of a transistor is not defined); "What is the current thru node 1?" (Nodes are places where voltage is measured and may have numerous wires associated with them); "What is R9?" (R9 is a resistor); "Is Q5 conducting?" (The laboratory section of SOPHIE gives information that is directly available from a real lab such as currents and voltages.)

(4) Gross misconceptions whose underlying meaning is well beyond designed system capabilities - "Make the output voltage 30 volts"; "Turn on the power supply and tell me how the unit functions"; "What time is it?".

The best technique for dealing with each type of error is an open problem. In the remainder of this section, we will discuss the solutions used in the SOPHIE system to provide feedback.

The use of a spelling correction algorithm (borrowed from INTERLISP) has proven to be a satisfactory solution to type 1 errors. During one student's session, spelling correction was required on, and resulted in proper understanding of, 10% of the questions. The major failings of the

INTERLISP algorithm are the restriction on the size of the target set of correct words (time increases linearly with the number of words) and its failure to correct run-on words. (The time required to determine if a word may be two (possibly misspelled) words run together increases very quickly with the length of the word and the number of possibly correct words. With no context to restrict the possible list of words, the computation involved is prohibitive.) A potential solution to both shortcomings would be to use the context of the parser to reduce the possibilities when it reaches the unknown word. Because of the nature of the grammar, this would allow semantic context as well as syntactic context to be used.

Of course, the use of any spelling correction procedure has some dangers. A word that is spelled correctly but that the system doesn't know may be changed through spelling correction to a word the system does know. For example if the system doesn't know the word "top" but does know "stop", a user's command to "top everything" can be disastrously misunderstood. For this reason, words like "stop" are not spelling corrected.

Our solution to predictable misconceptions (type 3 errors) is to recognize them and give error messages that are directed at correcting the misconception. We are currently using two different methods of recognition. One is to loosen up the grammar so that it accepts plausible but meaningless sentences. This technique provides the procedural specialists called by the plausible parse enough context to make relevant comments. For example, the concept of current through a node is accepted by the grammar even though it is meaningless. The specialist that performs measurements must then check its arguments and provide feedback if necessary:

```
>> WHAT IS THE CURRENT THRU NODE 4?

The current thru a node is not meaningful since by Kirchoff's law
the sum of the currents thru any node is zero. Currents can be
measured thru parts (e.g. CURRENT THRU C6) or terminals
(e.g. CURRENT THRU THE COLLECTOR OF Q2).
```

Notice that the response to the question presents some examples of how to measure the currents along wires that lead into the mentioned node. Examples of questions that will be accepted and are relevant to the student's needs are among the best possible feedback.

The second method of recognizing common misconceptions is to "key" feedback off single words or groups of words. In the following examples, the "keys" are "or" and "turned on". Notice that the response presents a general characterization of the violated limitations as well as suggestions for alternative lines of attack.

>> COULD Q1 OR Q2 BE SHORTED?

> I can only handle one question, hypothesis, etc. at a time. The fact that you say 'OR' indicates that you may be trying to express two concepts in the same sentence. Maybe you can break your statement into two or more simple ones.

>> IS THE CURRENT LIMITING TRANSISTOR TURNED ON?

> The laboratory section of SOPHIE is designed to provide the same elementary measurements that would be available in a real lab. If you want to determine the state of a transistor, measure the pertinent currents and voltages.

These methods of handling type 3 errors have proved to be very helpful. However, they require that all of the misconceptions must be predicted and programmed for in advance. This limitation makes them inapplicable to novel situations.

The most severe problems a user has stem from type 2 (omissions) and type 4 (major misconceptions) errors. (Type 3 errors that haven't been predicted are considered type 4 errors.) After a simple omission, the user may not see that he has left anything out and may conclude that the system doesn't know that concept or phrasing of that concept. For example when the user types "What is the BE of Q5" instead of "What is the VBE of Q5?", he may decide that it is unacceptable because the system doesn't allow "VBE" as an abbreviation of "base emitter voltage". For type 4 errors, the user may waste a lot of time and energy attempting several rephrasings of his query, none of which can be understood because the system doesn't know the concept the user is trying to express. For example, no matter how it is phrased, the system won't understand "Make the output voltage 30 volts" because measurements cannot be directly changed, only controls and specifications of parts can be changed.

The feedback necessary to correct both of these classes of errors must identify any concepts in the statement that are understood and suggest the range of things that can be done to/with these concepts. For type 2 errors, this will help the user see his omission. For type 4 errors, it may suggest alternative conceptualizations that will allow the user to get at the same information (for example, to change the output voltage indirectly by changing one of the controls) or at least provide him with enough information to decide when to quit.

The notion of semantic grammar may be useful in developing a general solution along the following lines: A bottom-up or island parsing scheme could be used to identify well-formed constituents.(27) Since the grammar is semantically based, the constituents that are found represent "islands" of meaningful phrases. The ATN representation of the semantic grammar can then be inspected to discover possible ways of combining these islands. If a good match is found, the grammar can be used to generate a response that indicates what other semantic parts are required for that rule. Even if no good matches are found, a positive statement may be made that explains the set of possible ways the recognized structures could be understood. Much more work is required in the area of unacceptable inputs before natural language systems will feel really natural to naive users.

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(27) William Woods and Geoff Brown are presently refining such a bottom-up parsing technique for ATN grammars for use in the BBN Speech project (Woods 1976).

Chapter 7

CONCLUDING DISCUSSION

Future Research Areas

The SOPHIE semantic grammar system is designed for a particular context -- trouble shooting -- within a particular domain, namely, electronics. It represents the compilation of those pieces of knowledge which are general (linguistic) together with specific domain dependent knowledge. In its present form, it is unclear which knowledge belongs to which area. The development of semantic grammars for other applications and extensions to the semantic grammar mechanism to include other understood linguistic phenomena will clarify this distinction.

While the work presented in this report has dealt mostly on one area of application, the notion of semantic grammar as a method of integrating knowledge into the parsing process has wider applicability. Two alternative applications of the technique have been completed. One deals with simple sentences in the domain of attribute blocks (Brown et al. 1975). While the sublanguage accepted in the attribute blocks environment is very simple, it is noteworthy that within the semantic grammar paradigm, a simple grammar was quickly developed that greatly improved the flexibility of the input language. The other completed application deals with questions about the editing system NLS (Grignetti et al. 1975). In this application, most questions dealt with editing commands and their arguments, and fit nicely into the case frame notion mentioned in Chapter 5. The case frame use of semantic grammar is being considered for, and may have its greatest impact on, command languages. Command languages are typically case centered around the command name that requires additional arguments (its cases). The combination of the semantic classification provided by the semantic grammar and the representation of case rules permitted by ATNs should go a long way towards reducing the rigidity of complex command languages such as those required for message processing systems. The combination should also be a good representation for natural language systems in domains where it is possible to develop a strong underlying conceptual space, such as management information systems (Malhotra 1975).

The extension of the semantic grammar to incorporate existing linguistic processing techniques is another potentially fruitful research area. One of the ways semantic grammar gains efficiency is to separate the processing of syntactically similar sentences on semantic grounds when it is useful to do so. However, this prevents the uniform incorporation of, for example, Woods' (1973b) solution to the problems of relative clause modification, quantifiers and conjunction. One means of integrating these techniques would be to develop an intermediate target language that maintains the advantages of the semantic grammar approach while allowing uniform solutions to other problems. It may even be possible to adopt Woods' query language, allowing the semantic grammar to dictate the functions within the "propositions" and "commands". An alternative attack would be to use a "syntactic" processing phase, incorporating the desired techniques that canonicalizes the input before it is processed by the semantic grammar. In this method, the semantic grammar would be viewed as an interpretation phase of the understanding process, but which works on a much less structured syntactic parse than, for example, the LUNAR system.

CONCLUSIONS

In the course of this report, we have described the evolution of a natural language front-end from keyword beginnings to a system capable of using complex linguistic knowledge. The guiding strand has been the utilization of semantic information to produce efficient natural language processors. There were several highlights that represent noteworthy points in the spectrum of useful natural language systems. Toward the keyword end of the scale, the procedural encoding technique with fuzziness (Chapter 4 and Appendix B) allows simple natural language input to be accepted without introducing the complexity of a new formalism. Encoding the rules as procedures allowed flexible control of the fuzziness and the semantic nature of the rules provides the correct places to take advantage of the flexibility. As the language covered by the system becomes more complex, the additional burden of a grammar formalism will more than pay for itself in terms of ease of development and reduction in complexity. The ATN compiling system allows for the consideration of the ATN formalism by reducing its runtime cost, making it comparable to a direct procedural encoding. The natural language front end now used by SOPHIE is constructed by compiling a semantic ATN. As the linguistic complexity of the language accepted by the system increases, the need for more syntactic knowledge in the grammar becomes greater. Unfortunately, this often works at cross purposes with the semantic character of the grammar. It would be nice to have a general grammar for English syntax that could be used to preprocess sentences; however, one is not forthcoming. A general solution to the problem of incorporating semantics with the current state of incomplete knowledge of syntax remains an open research problem. In the foreseeable future, any system will have to be an engineering trade-off between complexity and generality on one hand and efficiency and habitability on the other. We have presented several techniques that are viable bargains in this trade-off.

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Appendix A

BNF Description of Part of the SOPHIE Semantic Grammar

This appendix gives a BNF-like description of part of the language accepted by SOPHIE. Included are all of the rules necessary to parse a "measurement". Examples of "measurements" are "voltage at N1", "base emitter current of Q5", and "output voltage". The grammar is implemented as LISP functions and an example is listed in Appendix B.

In the description, alternatives on the right-hand side are separated by ! or are listed on separate lines. Brackets [] enclose optional elements. An asterisk * is used to mark notes about a particular rule. Non-terminals are designated by names enclosed in angle brackets <>.

The Grammar

```
<circuit/place>:= <terminal> ! <node>

<diode/spec> := <diode> ! <zener/diode>
                <section> diode ! <section> zener/diode

<junction> := <junction/type> [of] <transistor/spec>
              <transistor/term/type> and <transistor/term/type> [of]
                    [<transistor/spec>]
              <transistor/term/type> to <transistor/term/type> [of]
                    [<transistor/spec>]

<junction/type> := eb ! be ! ec ! ce ! cb ! bc

<meas/quant> := voltage ! current ! resistance* ! power
                *means measured resistance

<measurement> := <section>[output*][<meas/quant>]
                 output* <meas/quant> [of] <section>
                 output* [<meas/quant>] [of <transformer>]
                 <transformer> <meas/quant>
                 <meas/quant> between** <circuit/place> and*
                   <circuit/place>
                 <meas/quant> of*** <part/spec>
                 <meas/quant> between output terminals
                 <meas/quant> of <junction>
                 <meas/quant> of <circuit/place>
                 <meas/quant> from <junction>
                 <meas/quant> of <section>
                 <meas/quant> of <pronoun>
                 <junction/type> <meas/quant> [of <transistor/spec>]
                 <transistor/term/type> <meas/quant> of
                   [<transistor/spec>]
                 *input also
                 **from-to also works
                 ***at, thru, in, into, across and through also work

<node> := junction of <part/spec> and <part/spec>
          node between <section> and <section>
          [point] between <part/spec> and <part/spec>
          <node/name> ! [node] <node/number>
          <pronoun>

<num/spec> := "any positive number" [k] ! one

<part/spec> := <part/name> ! <load/spec> ! <section> <part/type>
               <pronoun>
```

```
<pot/spec> := cc ! vc ! cct

<pronoun>:= it ! [that] "type"

<terminal> := output [terminal] ! <transistor/term> ! center/tap
              positive terminal [<part/spec>] ! positive one
              negative terminal [<part/spec>] ! negative one
              anode [<diode/spec>] ! cathode [<diode/spec>]
              wiper [<pot/spec>]

<transistor/spec> := <transistor> ! <section> transistor ! <pronoun>

<transistor/term> := <transistor/term/type> [<transistor/spec>]

<transistor/term/type> := base ! collector ! emitter
```

<transistor>, <capacitor>, <diode>, <resistor>, <transformer> and <zener/diode> all check the semantic network and parse correct part names, e.g. r9, q6.

<section> uses the semantic network to determine if a word is a section of the unit, e.g. current/limiter.

<part/name> uses the semantic network to see if a word is the name of a part e.g. r6, c4, t2.

<node/name> checks semantic network for node names.

Appendix B

A LISP Rule from the Semantic Grammar

This appendix describes the method of encoding the grammar as LISP procedures. The ways of expressing a non-terminal are embodied in a grammar function. Each grammar function takes at least two arguments; STR, the list of words to be recognized, and N, the degree of fuzziness allowed. The grammar function, in effect, must determine whether the beginning of the string STR contains an occurrence of the corresponding non-terminal. There are generally two types of checks that a grammar function performs. One is a check for the occurrence of a word or words which satisfies certain predicates. This checking is done with two functions -- CHECKLST and CHECKSTR. CHECKLST looks for a word in the string matching any of a list of words. CHECKSTR looks for a word in the string satisfying an arbitrary predicate. It is through these functions that the parser implements its fuzziness. For example, if CHECKSTR is called with the string "resistor R9" and a predicate which determines if a word is the name of a part (e.g. "R9"), CHECKSTR will succeed by skipping the word "resistor", which in this phrase, is a noise word.

The other usual type of operation performed by the grammar functions is to check for the occurrence of other non-terminals. This is done by calling the proper function (grammar rule) and passing it the correct position in the input string.

If a grammar rule is successful, the function passes back two pieces of information. First, it returns some indication of how much of the input string is accepted (i.e. where it stopped). The convention adopted is that the grammar rule returns as its value a pointer to the last word in the string accepted by the rule. Second, the function passes back a structural description of the phrase that was parsed. This structure is passed back in the free variable RESULT (analogous to an ATN's "*" upon return from a PUSH.

Listed below is the grammar rule for the concept of a junction of a transistor. This rule accepts phrases such as "base emitter junction of Q5", "BE of the current limiting transistor", or "collector emitter junction".

```
(<JUNCTION>
 [LAMBDA (STR N)
  (PROG (TS1 R1)
      (RETURN
      (AND

(* COMMENT A)

         [OR (AND (SETQ TS1 (<JUNCTION/TYPE> STR N))
                  (SETQ R1 RESULT))
             (AND (SETQ TS1 (<TRANSISTOR/TERM/TYPE> STR N))
                  (SETQ R1 RESULT)
                  [SETQ TS1
                    (<TRANSISTOR/TERM/TYPE>
                      (CDR (CHECKLST (CDR TS1)
                                     (QUOTE (AND TO]
                  (SETQ R1 (JUNCTION-OF-TERMS R1 RESULT]

(* COMMENT B)

         (COND
           ([SETQ STR (<TRANSISTOR/SPEC>
                  (CDR (GOBBLE (GOBBLE TS1 (QUOTE (JUNCTION)))
                               (QUOTE (OF))
                               1]
             (SETQ RESULT (LIST R1 RESULT))
             STR)
```

```
([SETQ RESULT (LIST R1 (LIST (QUOTE PREF)
                             (QUOTE (TRANSISTOR]
  TS1]))
```

COMMENT A:

The first thing that is looked for is either a <junction/type> (BE, emitter collector, etc.) or two <transistor/terminal/type>s (base, emitter or collector) separated by the words "and" or "to". If two terminals are found, the function JUNCTION-OF-TERMS is called to determine the proper junction. In either case, the place where the successful subsidiary rule left off is saved in TS1 and the meaning of the accepted phrase is saved in R1.

COMMENT B:

The next thing needed for a junction is a transistor <TRANSISTOR/SPEC>. <TRANSISTOR/SPEC> looks for an occurrence of a transistor, e.g. "Q5" or "current limiting transistor". GOBBLE is a function for skipping relational words when they are not used to restrict the remaining part of the phrase. If a transistor is not found, a deletion is hypothesized and a call to PREF is constructed. If the transistor has been pronominalized as in "the base emitter of it", <TRANSISTOR/SPEC> would recognize "it". In either case the semantics of the recognized phrase (something like (EB Q5)) is put into RESULT and a pointer to the last recognized word is returned as the value of <JUNCTION>.

There are approximately 80 grammar rules in SOPHIE's grammar.

Appendix C

Sample Parses and Parse Times for the LISP Implementation

This appendix presents some examples of sentences handled by the natural language processor together with their parse times. Under each statement, the semantic interpretation returned by the parser is given. The semantic interpretation is a function call which when evaluated performs the processing required by the statement. Parse times are given in milliseconds.

Insert a fault.

```
(INSERTFAULT NIL)
```

85 ms

What is the output voltage?

```
(MEASURE VOLTAGE NIL OUTPUT)
```

40 ms

What is the voltage between the current limiting transistor and the constant current source?

```
(MEASURE VOLTAGE (NODE/BETWEEN
                    (FINDPART CURRENT/LIMITER TRANSISTOR)
                     CURRENT/SOURCE))
```

335 ms

What is the voltage between there and the base of Q6?

```
(MEASURE VOLTAGE (PREF (NODE TERMINAL)) (BASE Q6))
```

80 ms

Q5?

```
(REFERENCE ((TRANSISTOR) Q5))
```

60 ms

Could the problem be that Q5 is bad?

```
(TESTFAULT Q5 BAD)
```

100 ms

Could it be shorted?

```
(TESTFAULT (PREF (PART JUNCTION TERMINAL)) SHORT)
```

75 ms

If R8 were 30k what would the output voltage be?

```
(IFTHEN (R8 30000.0 VALUE)
        (MEASURE VOLTAGE NIL OUTPUT))
```

220 ms

If C2 were leaky what would the voltage across it be?

```
(IFTHEN (C2 LEAKY)
        (MEASURE VOLTAGE (PREF (PART JUNCTION)))
```

120 ms

What is the output voltage when the voltage control is set to .5?

```
(RESETCONTROL (STQ VC .5)
              (MEASURE VOLTAGE NIL OUTPUT))
```

85 ms

What is it with it set at .6?

```
(RESETCONTROL (STQ (PREF (POT LOAD SWITCH)) .6)
              (REFERENCE NIL))
```

110 ms

If it is set to .9?

```
(RESETCONTROL (STQ (PREF (POT LOAD SWITCH)) .9)
              (REFERENCE NIL))
```

135 ms

What is the current thru the cc when the vc is set to 1.0?

```
(RESETCONTROL (STQ VC 1.0)
              (MEASURE CURRENT CC))
```

190 ms

If Q6 has an open emitter and a shorted base collector junction, what happens to the voltage between its base and the junction of the voltage limiting section and the voltage reference source?

```
(IFTHEN
      (MULT ((EMITTER Q6) OPEN)
            ((BC (PREF (TRANSISTOR))) SHORT))
      (MEASURE VOLTAGE
               (BASE (PREF (TRANSISTOR)))
               (NODE/BETWEEN VOLTAGE/LIMITER REFERENCE/VOLTAGE)))
```

400 ms.

Appendix D

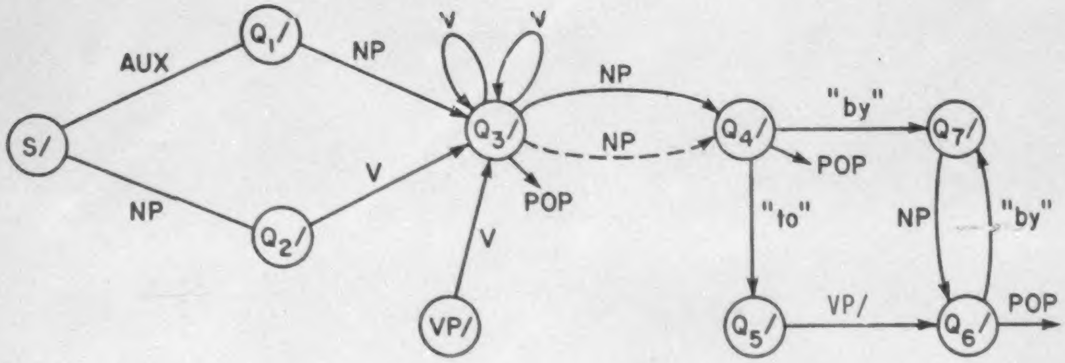
Examples of ATN Compilation

This appendix presents a simple augmented transition network grammar along with two different programs compiled from it and a trace of the first program parsing a sentence. The ATN grammar was taken from (Woods 1970). Both compiled versions of the grammar assume a depth-first search strategy and use configurations which include the state, node, stack, registers, features and hold list.

The first program does not support lexical ambiguity (neither that caused by compound rules nor that caused by multiple interpretations under the same category). In addition, it neither keeps a well-formed substring table, tests for input before pushing nor returns features with popped constituents. The second program, on the other hand, has all of these capabilities. The listing of the second program also includes tracing functions the compiler includes in the program to allow the user to follow its operation. Both programs are given in CLISP (Teitelman 1974).

The final section of the appendix contains a trace of the first program (using a version which did include tracing functions) discovering all possible parses of the sentence "John was believed to have been shot by Fred". Shown in the trace are all of the arc transitions taken by the parser together with all register setting operations. (The reader may compare this with the analysis of this sentence given in (Woods 1970).)

The grammar


S/
AUX
Q1/
NP
NP
Q2/
V
V
V
Q3/
NP
NP
POP
V
VP/
Q4/
"by"
POP
"to"
Q7/
NP
"by"
Q5/
VP/
Q6/
POP

```
(S/
   (CAT AUX T
        (SETR V *)
        (SETR TNS (LIST (GETF * TENSE)))
        (SETRQ TYPE Q)
        (TO Q1/))
   (PUSH NP/ T
        (SETR SUBJ *)
        (SETRQ TYPE DCL)
        (TO Q2/)))
(Q1/
   (PUSH NP/ T
        (SETR SUBJ *)
        (TO Q3/)))
(Q2/
   (CAT V T
        (SETR V *)
        (SETR TNS (LIST (GETF * TENSE)))
        (TO Q3/)))
(Q3/
   (CAT V (AND (GETF * PPRT)
               (EQ (GETR V)
                   (QUOTE BE)))
        (HOLD (GETR SUBJ))
        (SETR SUBJ (BUILDQ (NP (PRO SOMEONE))))
        (SETR AGFLAG T)
        (SETR V *)
        (TO Q3/))
   (CAT V (AND (GETF * PPRT)
               (EQ (GETR V)
                   (QUOTE HAVE)))
        (SETR TNS (APPEND (GETR TNS)
                          (QUOTE (PERFECT))))
        (SETR V *)
        (TO Q3/))
   (PUSH NP/ (TRANS (GETR V))
        (SETR OBJ *)
        (TO Q4/))
   (VIR NP (TRANS (GETR V))
        (SETR OBJ *)
        (TO Q4/))
   (POP (BUILDQ (S + + (TNS +) (VP (V +)))
                TYPE SUBJ TNS V)
       (INTRANS (GETR V))))
```

```
(Q4/
   (WRD BY (GETR AGFLAG)
        (SETR AGFLAG NIL)
        (TO Q7/))
   (WRD TO (S-TRANS (GETR V))
        (TO Q5/))
   (POP (BUILDQ (S + + (TNS +) (VP (V +) +))
                TYPE SUBJ TNS V OBJ)
       T))
(Q5/
   (PUSH VP/ T
        (SENDR SUBJ (GETR OBJ))
        (SENDR TNS (GETR TNS))
        (SENDRQ TYPE DCL)
        (SETR OBJ *)
        (TO Q6/)))
(Q6/
   (WRD BY (GETR AGFLAG)
        (SETR AGFLAG NIL)
        (TO Q7/))
   (POP (BUILDQ (S + + (TNS +) (VP (V +) +))
                TYPE SUBJ TNS V OBJ)
       T))
(Q7/
   (PUSH NP/ T
        (SETR SUBJ *)
        (TO Q6/)))
(VP/
   (CAT V (GETF * UNTENSED)
        (SETR V *)
        (TO Q3/)))
(NP/
   (CAT DET T
        (SETR DET *)
        (TO NP/1))
   (CAT NPR T
        (SETR NPR *)
        (TO NP/3)))
(NP/1
   (CAT ADJ T
        (ADDL ADJS *)
        (TO NP/1))
   (CAT N T
        (SETR N *)
        (TO NP/2)))
(NP/2
   (POP (BUILDQ (NP (DET +) (ADJ +) (N +))
                DET ADJS N)
       T))
(NP/3
   (POP (BUILDQ (NP (NPR +))
                NPR)
       T))
)
```

Version I

```
(PARSER
  (LAMBDA (ACF)
    (PROG (STATE NODE STACK REGS HOLD * LEX)
```

The current status of the machine is kept in five global variables; (1) STATE, the state/arc in the grammar, ([illegible] NODE, the pointer into the input, (3) REGS, the list of register name-value pairs, (4) STACK, the return stack, and (5) HOLD, the hold list. Putting the machine into a given configuration involves assigning values of these five variables.

```
SPREAD-ACF
     (STATE←(CF.STATE ACF))
     (REGS←(CF.REGS ACF))
     (STACK←(CF.STACK ACF))
     (HOLD←(CF.HOLD ACF))
     (NODE←(CF.NODE ACF))
     (LEX←(EDGE.WORD (FIRST.EDGE NODE)))
```

BRANCH dispatches control to the label specified by STATE. This is the method of executing an arc.

```
EVALARC
     (BRANCH STATE SUCCESS DETOUR S/ S/-2 S/-2-PUSH Q1/
             Q1/-1-PUSH Q2/ Q3/ Q3/-2 Q3/-3 Q3/-4 Q3/-5
             Q3/-3-PUSH Q4/ Q4/-2 Q4/-3 Q5/ Q5/-1-PUSH Q6/
             Q6/-2 Q7/ Q7/-1-PUSH VP/ NP/
             NP/-2 NP/1 NP/1-2 NP/2 NP/3)
```

SUCCESS checks to make sure all of the input has been processed. If not it detours.

```
SUCCESS
     (if (EMPTYP.NODE NODE)
          then (RETURN *)
        else (GO DETOUR))
```

DETOUR decides which alternative to try next. In this case the alternatives list is a stack.

```
DETOUR
     (if ALTS
          then ACF←(ALTS.FIRST)
               (ALTS.BUTFIRST)
               (GO SPREAD-ACF)
        else (RETURN (FAILURE)))
```

This is the beginning of the code which is compiled from the arcs. The first arc of each state has a label which is the same as the state name in the ATN. The other arcs have a label which is the state name followed by "-" and the arc number. Labels which end in "-PUSH" indicate the actions and termination action of PUSH arcs.

```
S/  (if (ARCCAT AUX)
          then (ALTARÇ S/-2)
               (SETR ´V *)
               (SETR ´TNS <(GETF * ´TENSE)>)
               (SETRQ TYPE Q)
               (DOTO Q1/)
               (GO Q1/))
```

```
S/-2(DOPUSH NP/ S/-2-PUSH)
    (GO NP/)
S/-2-PUSH
    (SETR 'SUBJ *)
    (SETRQ TYPE DCL)
    (DOPTO Q2/)
    (GO Q2/)
Q1/ (DOPUSH NP/ Q1/-1-PUSH)
    (GO NP/)
Q1/-1-PUSH
    (SETR 'SUBJ *)
    (DOPTO Q3/)
    (GO Q3/)
Q2/ (if (ARCCAT V)
        then (SETR 'V *)
             (SETR 'TNS <(GETF * 'TENSE)>)
             (DOTO Q3/)
             (GO Q3/))
    (GO DETOUR)
Q3/ (while (ARCCAT V) and (GETF * 'PPRT)
                      and (GETR V)='BE
       do (ALTARC Q3/-2)
          (HOLD (GETR SUBJ))
          (SETR 'SUBJ (BUILDQ (NP (PRO SOMEONE))))
          (SETR 'AGFLAG T)
          (SETR 'V *)
          (DOTO Q3/))
Q3/-2
    (if (ARCCAT V) and (GETF * 'PPRT)
                   and (GETR V)='HAVE
        then (ALTARC Q3/-3)
             (SETR 'TNS <! (GETR TNS) ! '(PERFECT)>)
             (SETR 'V *)
             (DOTO Q3/)
             (GO Q3/))
Q3/-3
    (if (TRANS (GETR V))
        then (ALTARC Q3/-4)
             (DOPUSH NP/ Q3/-3-PUSH)
             (GO NP/))
Q3/-4
         (if (HOLDSCAN HOLD 'NP '(TRANS (GETR V)))
        then (ALTARC Q3/-5)
             (PREVIRACTS)
             (SETR 'OBJ *)
             (DOVIRTO Q4/)
             (GO Q4/))
Q3/-5
    (if (INTRANS (GETR V))
        then (DOPOP (BUILDQ (S + +(TNS +) (VP (V +)))
                            TYPE SUBJ TNS V))
             (GO EVALARC))
    (GO DETOUR)
Q3/-3-PUSH
    (SETR 'OBJ *)
    (DOPTO Q4/)
    (GO Q4/)
Q4/ (if (ARCWRD BY) and (GETR AGFLAG)
        then (ALTARC Q4/-2)
             (SETR 'AGFLAG NIL)
             (DOTO Q7/)
             (GO Q7/))
    Q4/-2
        (if (ARCWRD TO) and (S-TRANS (GETR V))
            then (ALTARC Q4/-3)
                 (DOTO Q5/)
                 (GO Q5/))
    Q4/-3
        (DOPOP (BUILDQ (S + +(TNS +) (VP (V +)+))
                       TYPE SUBJ TNS V OBJ))
        (GO EVALARC)
    Q5/ (SENDR 'SUBJ (GETR OBJ))
        (SENDR 'TNS (GETR TNS))
        (SENDRQ TYPE DCL)
        (DOPUSH VP/ Q5/-1-PUSH)
        (SREGS NIL)
        (GO VP/)
    Q5/-1-PUSH
        (SETR 'OBJ *)
        (DOPTO Q6/)
        (GO Q6/)
    Q6/ (if (ARCWRD BY) and (GETR AGFLAG)
            then (ALTARC Q6/-2)
                 (SETR 'AGFLAG NIL)
                 (DOTO Q7/)
                 (GO Q7/))
    Q6/-2
        (DOPOP (BUILDQ (S + +(TNS +)
                            (VP (V +)+))
                       TYPE SUBJ TNS V OBJ))
        (GO EVALARC)
    Q7/ (DOPUSH NP/ Q7/-1-PUSH)
        (GO NP/)
    Q7/-1-PUSH
        (SETR 'SUBJ *)
        (DOPTO Q6/)
        (GO Q6/)
    VP/ (if (ARCCAT V) and (GETF * 'UNTENSED)
            then (SETR 'V *)
                 (DOTO Q3/)
                 (GO Q3/))
        (GO DETOUR)
    NP/ (if (ARCCAT DET)
            then (ALTARC NP/-2)
                 (SETR 'DET *)
                 (DOTO NP/1)
                 (GO NP/1))
    NP/-2
        (if (ARCCAT NPR)
            then (SETR 'NPR *)
                 (DOTO NP/3)
                 (GO NP/3))
        (GO DETOUR)
    NP/1(while (ARCCAT ADJ) do (ALTARC NP/1-2)
                               (ADDL 'ADJS *)
                               (DOTO NP/1))
    NP/1-2
        (if (ARCCAT N)
            then (SETR 'N *)
                 (DOTO NP/2)
                 (GO NP/2))
        (GO DETOUR)
    NP/2(DOPOP (BUILDQ (NP (DET +)
                           (ADJ +)
                           (N +))
                       DET ADJS N))
        (GO EVALARC)
    NP/3(DOPOP (BUILDQ (NP (NPR +))
                       NPR))
        (GO EVALARC))))
)
```

Version II

```
(PARSER
  (LAMBDA (ACF)
    (PROG (STATE NODE STACK REGS FEATS HOLD * LEX SREGS
                SFEATS FEATURES TEMP)
```

If the function is called with an argument of ´GO, it looks for another parse. This allows the user to get out more than the first parse.

```
          (if ACF=´GO
              then (GO DETOUR))
```

The current status of the machine is kept in five global variables: (1) STATE, the state/arc in the grammar, (2) NODE, the pointer into the input, (3) REGS, the list of register name-value pairs, (4) STACK, the return stack, and (5) HOLD, the hold list. Putting the machine into a given configuration involves assigning values to these five variables.

```
      SPREAD-ACF
          (CHANGESTATE (CF.STATE ACF))
          (REGS←(CF.REGS ACF))
          (FEATS←(CF.FEATS ACF))
          (STACK←(CF.STACK ACF))
          (HOLD←(CF.HOLD ACF))
          (LEX←(EDGE.WORD (FIRST.EDGE NODE←(CF.NODE ACF))))
```

TRACEALTSTART is one of the tracing functions provided to allow the user to follow the operations of the parser. The others are TRACEARC and ABORT. None of these result in any code when a fast version of the parser is produced.

```
          (TRACEALTSTART)
          (GO EVALARC)
      NEXTLEX
```

If the current node has more than one lexical interpretation (BUTFIRST.EDGE), the code sets NODE to try the next one.

```
          (if (BUTFIRST.EDGE NODE)
              then LEX←(EDGE.WORD (FIRST.EDGE
                                     NODE←(BUTFIRST.EDGE
                                               NODE)))
                   (GO EVALARC))
```

BRANCH dispatches control to the label specified by STATE.

```
      EVALARC
          (BRANCH STATE SUCCESS DETOUR S/ S/-1-CONT S/-2
                  S/-1-CAT  S/-2-PUSH Q1/ Q1/-1-PUSH Q2/
                  Q2/-1-CONT Q2/-1-CAT Q3/ Q3/-1-CONT
                  Q3/-2 Q3/-2-CONT Q3/-3 Q3/-4 Q3/-5
                  Q3/-1-CAT Q3/-2-CAT Q3/-3-PUSH Q4/ Q4/-2 Q4/-3
                  Q5/ Q5/-1-PUSH Q6/ Q6/-2 Q7/ Q7/-1-PUSH
                  VP/ VP/-1-CONT VP/-1-CAT NP/ NP/-1-CONT
                  NP/-2 NP/-2-CONT NP/-1-CAT NP/-2-CAT
                  NP/1 NP/1-1-CONT NP/1-2 NP/1-2-CONT
                  NP/1-1-CAT NP/1-2-CAT NP/2 NP/3)
      SUCCESS
          (RETURN NODE)
```

DETOUR chooses an alternative from the ALTS list. In this version the ALTS list is a stack. The detouring mechanism could be changed by redefining ALTS.FIRST and ALTS.BUTFIRST. If there are no more alternatives, the first alternative from the list of SUSPENDED alts is taken. The suspended alternatives are maintained in order by weight.

```
ABORT
    (ABORT)                                   ABORT is a tracing function.
DETOUR
    (if ALTS
        then ACF←(ALTS.FIRST)
             (ALTS.BUTFIRST)
             (GO SPREAD-ACF)
      elseif SUSPENDEDALTS
        then ACF←(SUSPEND.POP)
             (GO SPREAD-ACF)
      else  (RETURN (FAILURE)))
S/  (if (ARCCAT AUX)
      else (GO S/-2))
    (ALTARC S/-2)
    (TRACEARC CAT AUX S/-1)
S/-1-CONT
    (ALTCAT S/-1-CAT)
    (SETR 'V *)
    (SETR 'TNS <(GETF * 'TENSE)>)
    (SETRQ TYPE Q)
    (DOTO Q1/)
    (GO Q1/)
S/-2(if (STRINGLEFTP)
        then (NEXTLEXALT S/)
             (TRACEARC PUSH NIL S/-2)
             (DOPUSH NP/ S/-2-PUSH)
             (GO DETOUR))
    (CHANGESTATEQ S/)
    (GO NEXTLEX)
S/-1-CAT
    (ARCCAT AUX)
    (TRACEARC ALTCAT AUX S/-1)
    (GO S/-1-CONT)
S/-2-PUSH
    (SPREAD/WFS)
    (SETR 'SUBJ *)
    (SETRQ TYPE DCL)
    (DOPTO Q2/)
    (GO Q2/)
Q1/ (if (STRINGLEFTP)
        then (NEXTLEXALT Q1/)
             (TRACEARC PUSH NIL Q1/-1)
             (DOPUSH NP/ Q1/-1-PUSH)
             (GO DETOUR))
    (CHANGESTATEQ Q1/)
    (GO NEXTLEX)
Q1/-1-PUSH
    (SPREAD/WFS)
    (SETR 'SUBJ *)
    (DOPTO Q3/)
    (GO Q3/)
Q2/ (if (ARCCAT V)
      else (CHANGESTATEQ Q2/)
           (GO NEXTLEX))
    (NEXTLEXALT Q2/)
    (TRACEARC CAT V Q2/-1)
```

```
Q2/-1-CONT
    (ALTCAT Q2/-1-CAT)
    (SETR ´V *)
    (SETR ´TNS <(GETF * ´TENSE)>)
    (DOTO Q3/)
    (GO Q3/)
Q2/-1-CAT
    (ARCCAT V)
    (TRACEARC ALTCAT V Q2/-1)
    (GO Q2/-1-CONT)
Q3/ (if (ARCCAT V)
      else (GO Q3/-2))
    (ALTARC Q3/-2)
    (TRACEARC CAT V Q3/-1)
Q3/-1-CONT
    (ALTCAT Q3/-1-CAT)
    (if ~((GETF * ´PPRT) and (GETR V)=´BE)
        then (GO ABORT))
    (HOLD (GETR SUBJ))
    (SETR ´SUBJ (BUILDQ (NP (PRO SOMEONE))))
    (SETR ´AGFLAG T)
    (SETR ´V *)
    (DOTO Q3/)
    (GO Q3/)
Q3/-2
    (if (ARCCAT V)
      else (GO Q3/-3))
    (ALTARC Q3/-3)
    (TRACEARC CAT V Q3/-2)
Q3/-2-CONT
    (ALTCAT Q3/-2-CAT)
    (if ~((GETF * ´PPRT) and (GETR V)=´HAVE)
        then (GO ABORT))
    (SETR ´TNS <! (GETR TNS) ! ´
                 (PERFECT)>)
    (SETR ´V *)
    (DOTO Q3/)
    (GO Q3/)
Q3/-3
    (if (STRINGLEFTP) and (TRANS (GETR V))
        then (ALTARC Q3/-4)
             (TRACEARC PUSH NIL Q3/-3)
             (DOPUSH NP/ Q3/-3-PUSH)
             (GO DETOUR))
Q3/-4
    (if TEMP (HOLDSCAN HOLD ´NP ´(TRANS (GETR V)))
        then (ALTARC Q3/-5)
             (TRACEARC VIR NP Q3/-4)
             (PREVIRACTS)
             (SETR ´OBJ *)
             (DOVIRTO Q4/)
             (GO Q4/))
Q3/-5
    (if (INTRANS (GETR V))
        then (NEXTLEXALT Q3/)
             (TRACEARC POP NIL Q3/-5)
             (DOPOP (BUILDQ (S + +(TNS +)
                                  (VP (V +)))
                            TYPE SUBJ TNS V)
                    (GETR POPFEATS))
             (GO DETOUR))
    (CHANGESTATEQ Q3/)
    (GO NEXTLEX)
```

```
Q3/-1-CAT
    (ARCCAT V)
    (TRACEARC ALTCAT V Q3/-1)
    (GO Q3/-1-CONT)
Q3/-2-CAT
    (ARCCAT V)
    (TRACEARC ALTCAT V Q3/-2)
    (GO Q3/-2-CONT)
Q3/-3-PUSH
    (SPREAD/WFS)
    (SETR 'OBJ *)
    (DOPTO Q4/)
    (GO Q4/)
Q4/ (if (ARCWRD BY) and (GETR AGFLAG)
        then (ALTARC Q4/-2)
             (TRACEARC WRD BY Q4/-1)
             (SETR 'AGFLAG NIL)
             (DOTO Q7/)
             (GO Q7/))
Q4/-2
    (if (ARCWRD TO) and (S-TRANS (GETR V))
        then (ALTARC Q4/-3)
             (TRACEARC WRD TO Q4/-2)
             (DOTO Q5/)
             (GO Q5/))
Q4/-3
    (NEXTLEXALT Q4/)
    (TRACEARC POP NIL Q4/-3)
    (DOPOP (BUILDQ (S + +(TNS +)
                       (VP (V +)+))
                    TYPE SUBJ TNS V OBJ)
           (GETR POPFEATS))
    (GO DETOUR)
Q5/ (if (STRINGLEFTP)
        then (NEXTLEXALT Q5/)
             (TRACEARC PUSH NIL Q5/-1)
             (SENDR 'SUBJ (GETR OBJ))
             (SENDR 'TNS (GETR TNS))
             (SENDRQ TYPE DCL)
             (DOPUSH VP/ Q5/-1-PUSH)
             SREGS←NIL
             SFEATS←NIL
             (GO DETOUR))
    (CHANGESTATEQ Q5/)
    (GO NEXTLEX)
Q5/-1-PUSH
    (SPREAD/WFS)
    (SETR 'OBJ *)
    (DOPTO Q6/)
    (GO Q6/)
Q6/ (if (ARCWRD BY) and (GETR AGFLAG)
        then (ALTARC Q6/-2)
             (TRACEARC WRD BY Q6/-1)
             (SETR 'AGFLAG NIL)
             (DOTO Q7/)
             (GO Q7/))
Q6/-2
    (NEXTLEXALT Q6/)
    (TRACEARC POP NIL Q6/-2)
    (DOPOP (BUILDQ (S + +(TNS +)
                       (VP (V +)+))
                    TYPE SUBJ TNS V OBJ)
           (GETR POPFEATS))
    (GO DETOUR)
```

```
Q7/ (if (STRINGLEFTP)
         then (NEXTLEXALT Q7/)
              (TRACEARC PUSH NIL Q7/-1)
              (DOPUSH NP/ Q7/-1-PUSH)
              (GO DETOUR))
    (CHANGESTATEQ Q7/)
    (GO NEXTLEX)
Q7/-1-PUSH
    (SPREAD/WFS)
    (SETR 'SUBJ *)
    (DOPTO Q6/)
    (GO Q6/)
VP/ (if (ARCCAT V)
       else (CHANGESTATEQ VP/)
            (GO NEXTLEX))
    (NEXTLEXALT VP/)
    (TRACEARC CAT V VP/-1)
VP/-1-CONT
    (ALTCAT VP/-1-CAT)
    (if ~(GETF * 'UNTENSED)
        then (GO ABORT))
    (SETR 'V *)
    (DOTO Q3/)
    (GO Q3/)
VP/-1-CAT
    (ARCCAT V)
    (TRACEARC ALTCAT V VP/-1)
    (GO VP/-1-CONT)
NP/ (if (ARCCAT DET)
       else (GO NP/-2))
    (ALTARC NP/-2)
    (TRACEARC CAT DET NP/-1)
NP/-1-CONT
    (ALTCAT NP/-1-CAT)
    (SETR 'DET *)
    (DOTO NP/1)
    (GO NP/1)
NP/-2
    (if (ARCCAT NPR)
       else (CHANGESTATEQ NP/)
            (GO NEXTLEX))
    (NEXTLEXALT NP/)
    (TRACEARC CAT NPR NP/-2)
NP/-2-CONT
    (ALTCAT NP/-2-CAT)
    (SETR 'NPR *)
    (DOTO NP/3)
    (GO NP/3)
NP/-1-CAT
    (ARCCAT DET)
    (TRACEARC ALTCAT DET NP/-1)
    (GO NP/-1-CONT)
NP/-2-CAT
    (ARCCAT NPR)
    (TRACEARC ALTCAT NPR NP/-2)
    (GO NP/-2-CONT)
NP/1(if (ARCCAT ADJ)
       else (GO NP/1-2))
    (ALTARC NP/1-2)
    (TRACEARC CAT ADJ NP/1-1)
NP/1-1-CONT
    (ALTCAT NP/1-1-CAT)
    (ADDL 'ADJS *)
    (DOTO NP/1)
    (GO NP/1)
```

```
     NP/1-2
         (if (ARCCAT N)
           else (CHANGESTATEQ NP/1)
                (GO NEXTLEX))
         (NEXTLEXALT NP/1)
         (TRACEARC CAT N NP/1-2)
     NP/1-2-CONT
         (ALTCAT NP/1-2-CAT)
         (SETR 'N *)
         (DOTO NP/2)
         (GO NP/2)
     NP/1-1-CAT
         (ARCCAT ADJ)
         (TRACEARC ALTCAT ADJ NP/1-1)
         (GO NP/1-1-CONT)
     NP/1-2-CAT
         (ARCCAT N)
         (TRACEARC ALTCAT N NP/1-2)
         (GO NP/1-2-CONT)
     NP/2(NEXTLEXALT NP/2)
         (TRACEARC POP NIL NP/2-1)
         (DOPOP (BUILDQ (NP (DET +)
                            (ADJ +)
                            (N +))
                        DET ADJS N)
                (GETR POPFEATS))
         (GO DETOUR)
     NP/3(NEXTLEXALT NP/3)
         (TRACEARC POP NIL NP/3-1)
         (DOPOP (BUILDQ (NP (NPR +))
                        NPR)
                (GETR POPFEATS))
         (GO DETOUR))))
)
```

Trace of Version I Parsing a Sentence

```
PARSE((JOHN WAS BELIEVED TO HAVE BEEN SHOT BY FRED))

Starting alternative 0
At arc S/
Node = (((JOHN NPR (&)) ((WAS V & AUX &) (& &))))
```

The sentence is converted into a chart format. The chart contains information about the possible parts of speech of each word. Notice that "was" can be either a verb (V) or an auxiliary verb (AUX). (An "&" is used to indicate a further structure.)

```
Taking PUSH arc S/-2
```

The trace indicates the arc type and its location in the grammar. No alternative is stored because S/-2 is the last arc in the state S/ and there are no lexical alternatives.

```
PUSHing for NP/
 Taking CAT NPR arc NP/-2
     Setting NPR to JOHN
```

The trace also indicates where registers get set.

```
Entering state NP/3
 Node = (((WAS V (&) AUX (&)) ((BELIEVED V &) (& &))))
 Taking POP arc NP/3-1
 Trying to POP
(Continuing arc S/-2-PUSH)
    Setting SUBJ to (NP (NPR JOHN))
    Setting TYPE to DCL

Entering state Q2/
Node = (((WAS V (&) AUX (&)) ((BELIEVED V &) (& &))))
Taking CAT V arc Q2/-1
    Setting V to BE
    Setting TNS to (PAST)

Entering state Q3/
Node = (((BELIEVED V (&)) ((TO PREP &) (& &))))
```

The alternative configuration to try the second arc leaving Q3/ (Q3/2) is created and saved after the test has succeeded on the first arc but before the arc is taken. This is alt 2 because configuration 1 was created during the earlier PUSH arc (i.e. the number is a configuration number).

```
        Storing alt 2 for arc Q3/-2
Taking CAT V arc Q3/-1
HOLDing (NP (NPR JOHN))
    Setting SUBJ to (NP (PRO SOMEONE))
    Setting AGFLAG to T
    Setting V to BELIEVE

Entering state Q3/
Node = (((TO PREP (&)) ((HAVE V &) (& &))))
        Storing alt 3 for arc Q3/-4
Taking PUSH arc Q3/-3
PUSHing for NP/
 BLOCKED

Starting alternative 3
At arc Q3/-4
```

```
Node = (((TO PREP (&)) ((HAVE V &) (& &))))
     Storing alt 5 for arc Q3/-5
Taking VIR NP arc Q3/-4
(NP (NPR JOHN)) removed from HOLD list
   Setting OBJ to (NP (NPR JOHN))

Entering state Q4/
Node = (((TO PREP (&)) ((HAVE V &) (& &))))
     Storing alt 6 for arc Q4/-3
Taking WRD TO arc Q4/-2

Entering state Q5/
Node = (((HAVE V (&)) ((BEEN V &) (& &))))
Taking PUSH arc Q5/-1
   SENDing SUBJ value of (NP (NPR JOHN))
   SENDing TNS value of (PAST)
   SENDing TYPE value of DCL
PUSHing for VP/
 Taking CAT V arc VP/-1
    Setting V to HAVE

Entering state Q3/
 Node = (((BEEN V (&)) ((SHOT V &) (& &))))
      Storing alt 8 for arc Q3/-3
 Taking CAT V arc Q3/-2
    Setting TNS to (PAST PERFECT)
    Setting V to BE

Entering state Q3/
 Node = (((SHOT V (&)) ((BY PREP &) (& NIL))))
      Storing alt 9 for arc Q3/-2
 Taking CAT V arc Q3/-1
 HOLDing (NP (NPR JOHN))
    Setting SUBJ to (NP (PRO SOMEONE))
    Setting AGFLAG to T
    Setting V to SHOOT

Entering state Q3/
 Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
      Storing alt 10 for arc Q3/-4
 Taking PUSH arc Q3/-3
 PUSHing for NP/
  BLOCKED

Starting alternative 10
At arc Q3/-4
Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
      Storing alt 12 for arc Q3/-5
 Taking VIR NP arc Q3/-4
 (NP (NPR JOHN)) removed from HOLD list
    Setting OBJ to (NP (NPR JOHN))

Entering state Q4/
 Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
      Storing alt 13 for arc Q4/-2
 Taking WRD BY arc Q4/-1
    Setting AGFLAG to NIL

Entering state Q7/
 Node = (((FRED NPR (&)) NIL))
 Taking PUSH arc Q7/-1
 PUSHing for NP/
  Taking CAT NPR arc NP/-2
    Setting NPR to FRED
```

```
Entering state NP/3
  Node = (NIL)
  Taking POP arc NP/3-1
  Trying to POP
 (Continuing arc Q7/-1-PUSH)
    Setting SUBJ to (NP (NPR FRED))

Entering state Q6/
 Node = (NIL)
 Taking POP arc Q6/-2
 Trying to POP
(Continuing arc Q5/-1-PUSH)
   Setting OBJ to (S DCL (NP (NPR FRED))
                         (TNS (PAST PERFECT))
                         (VP
(V SHOOT) (NP (NPR JOHN))))

Entering state Q6/
Node = (NIL)
Taking POP arc Q6/-2
Trying to POP
Trying to SUCCEED

S DCL
  NP PRO SOMEONE
  TNS PAST
  VP V BELIEVE
     S DCL
       NP NPR FRED
       TNS PAST PERFECT
       VP V SHOOT
          NP NPR JOHN

Starting alternative 13
At arc Q4/-2
Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
 Taking POP arc Q4/-3
 Trying to POP
(Continuing arc Q5/-1-PUSH)
   Setting OBJ to (S DCL (NP (PRO SOMEONE))
                         (TNS (PAST PERFECT))
                         (VP
(V SHOOT) (NP (NPR JOHN))))

Entering state Q6/
Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
      Storing alt 15 for arc Q6/-2
Taking WRD BY arc Q6/-1
   Setting AGFLAG to NIL

Entering state Q7/
Node = (((FRED NPR (&)) NIL))
Taking PUSH arc Q7/-1
PUSHing for NP/
 Taking CAT NPR arc NP/-2
    Setting NPR to FRED

Entering state NP/3
 Node = (NIL)
 Taking POP arc NP/3-1
 Trying to POP
(Continuing arc Q7/-1-PUSH)
   Setting SUBJ to (NP (NPR FRED))
```

One successful parse. Parser continues because it was being run in a mode which returns all possible parses.

```
Entering state Q6/
Node = (NIL)
Taking POP arc Q6/-2
Trying to POP
Trying to SUCCEED

S DCL
  NP NPR FRED
  TNS PAST
  VP V BELIEVE
     S DCL
       NP PRO SOMEONE
       TNS PAST PERFECT
       VP V SHOOT
          NP NPR JOHN
```

Second possible parse.

```
Starting alternative 15
At arc Q6/-2
Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
Taking POP arc Q6/-2
Trying to POP
Trying to SUCCEED
BLOCKED

Starting alternative 12
At arc Q3/-5
Node = (((BY PREP (&)) ((FRED NPR &) NIL)))
 BLOCKED

Starting alternative 9
At arc Q3/-2
Node = (((SHOT V (&)) ((BY PREP &) (& NIL))))
 BLOCKED

Starting alternative 8
At arc Q3/-3
Node = (((BEEN V (&)) ((SHOT V &) (& &))))
 BLOCKED

Starting alternative 6
At arc Q4/-3
Node = (((TO PREP (&)) ((HAVE V &) (& &))))
Taking POP arc Q4/-3
Trying to POP
Trying to SUCCEED
BLOCKED

Starting alternative 5
At arc Q3/-5
Node = (((TO PREP (&)) ((HAVE V &) (& &))))
BLOCKED

Starting alternative 2
At arc Q3/-2
Node = (((BELIEVED V (&)) ((TO PREP &) (& &))))
BLOCKED
NIL
```

Appendix E

Grammar Compiler Declarations

Specification of Features

Some features of the general ATN parser require a good deal of bookkeeping. For example, SYSCONJ requires a parser to save the path that it takes through the grammar. This more than doubles the amount of storage overhead. To relieve the burden of those features, such as SYSCONJ, which increase the overhead, and which a particular application may not require, the user can specify which features his grammar uses. The compiler will then tailor the object code to those needs. The user specifications consist of a collection of flags which are set at compile time. A description of each flag together with its default setting is given below.

HOLDFLG: If the grammar does not use the HOLD facility, setting this flag to NIL will eliminate one field in a configuration. Default is T.

FEATURESFLG: If the grammar doesn't use the feature facility, setting this flag to NIL will eliminate one field in a configuration. Default is T.

WFSTFLG: If the grammar uses the well-formed substring feature, WFSTFLG should be non-NIL. Default is NIL.

ALTCATSFLG: If this flag is NIL, the compiler will not compile the ability to handle multiple interpretations of a word *within a single category*. If ALTCATSFLG is a list, it will compile this ability into those CAT arcs whose categories are members of the list. If T, it will compile this ability into all CAT arcs. Default is T.

SYSCONJFLG: If the grammar uses the LUNAR SYSCONJ conjunction-handling facility SYSCONJFLG should be non-NIL. Default is NIL. (SYSCONJ has not been implemented yet.)

STARTSTATE: This should be the start state of the grammar. Default value is S/.

NULLPUSHFLG: If NULLPUSHFLG is non-NIL, a PUSH arc will never be taken if there is no input left.[1] Default setting is T.

UNAMBIGUOUS-CHART: If the input chart is never ambiguous, setting this flag to a non-NIL value will avoid the checking for an alternative lexical interpretation. Default is NIL.

---

[1] This begins to legislate out PUSHes which do not use any of the inputs. In practical terms, this means that a PUSHed to network has to do more than just take constituents off the hold list. In theoretical terms, it closes one of the holes which may allow an ATN grammar to be undecidable.

Declarations for Arc Tests and Actions

The tests and actions on an arc can be arbitrary LISP expressions. To compile these function calls, the grammar compiler must know which arguments get evaluated. In general the grammar compiler gets this information from the same declarations about functions that the LISP compiler uses (NLAMA, NLAML, FNTYPE, etc.). In addition a facility is provided which allows the user to tell the grammar compiler how to compile the individual arguments to particular functions. Using this facility it is possible to write function calls in the grammar which implicitly QUOTE some of their arguments and evaluate others or even which call another function to decode their arguments. The compiler is told how to compile the arguments to a function by putting a specification as the value of the property GRAMMARARGINFO on the property list of the function name. The value of GRAMMARARGINFO property should be one of the following:

1) LAMBDA: the function evaluates all of its arguments. (This is the default case.)

2) NLAMBDA: the function doesn't evaluate any of its arguments. This can also be done by putting the function on either of the lists NLAMA or NLAML (see INTERLISP compiler).

3) A list which specifies how each argument should be treated. Each element of the list can be:

   1) E or NIL - This argument position will be evaluated. This is the usual case where the action expects its argument to be evaluated and tells the grammar compiler to scan the argument for embedded calls.

   2) QUOTE - This argument is embedded in QUOTE. This provides a convenient way of automatically quoting certain argument positions in a function call.

   3) * - The argument is not compiled by the grammar compiler but is merely copied. Note: Arguments which occur in this position should not have any embedded functions as these will not be scanned by the compiler.

   4) Any other atom - The atom is the name of a function which when APPLYed to the argument returns the compiled form.

Examples: The grammar function SETR which sets the value of a register could be compiled by having a GRAMMARARGINFO property of (QUOTE E).[2] The arc action (SETR ANAPHORFLG T) would compile into (SETR (QUOTE ANAPHORFLG) T). SETR is defined as a LAMBDA function (i.e. the interpreter evaluates its arguments) which avoids the explicit call to EVAL which results from having SETR be a NLAMBDA function (i.e. the interpreter doesn't evaluate its arguments).

---

[2] SETR is, in fact, recognized specially by the grammar compiler so that it can keep track of the registers which are used in the grammar.

In the LUNAR grammar, many of the arc functions use EVALLOC to evaluate one or more of their arguments. EVALLOC has three options: (1) if its argument is "*" or NIL, it gets the value of the current thing - *; (2) if the argument is atomic, it is a register whose value is retrieved; and (3) if the argument is a list, it is evaluated. This allows the grammar to be clearer and less cluttered with predictable function calls. To accomplish the same results using the compiler, a version of EVALLOC (CEVALLOC) is provided which returns the form for the decoded argument. The functions which use it are then given GRAMMARARGINFO property of CEVALLOC for those argument positions which need decoding. This means that the decoding process takes place once at compile time instead of each time the arc is tried. For example, in the LUNAR grammar the function MARKER has a GRAMMARARGINFO property of (CEVALLOC QUOTE). This allows the grammar to have (MARKER N MASS) as an action which compiles into (MARKER (GETR N) (QUOTE MASS)) and avoids an explicit call to EVAL by MARKER. Notice that by using this technique, the grammar writer can easily specify default arguments to actions in his grammar (at very little computational cost) and greatly improve the readability of the grammar.

Appendix F

Debugging Features

Since the compiler transforms the grammar into a program, the grammar writer can use the debugging features of the object language to aid in debugging his grammar. These should, of course, be augmented by some features particular to grammars, but these are best integrated into an existing framework. The following section describes a collection of grammar debugging tools that have been integrated into the INTERLISP system.

The debugging facilities can be grouped into two major categories; tracing and breaking. The trace will show all grammar transitions and register-changing operations. In debugging mode, the system will even keep a complete history of the parse so that the user can back up. In addition, the user has the ability to stop the parser at the end of each line of the trace in order to look around in and/or change the current environment.

Tracing

The trace package causes the functions in the object language program to print out what they are doing. There are three types of actions which may be included in the trace: (1) arc transitions, storing of alternatives and hold list operations; (2) setting of registers; and (3) sending of registers to a PUSH configuration. The latter two of these can be turned off independently. In addition, the debugging system allows the user to trace to a disk file and not to TTY. (If the user wants both TTY and disk copies, he can use the INTERLISP DRIBBLE facility.)

Breaks

The break package allows the user to stop the parser at any time; check the states of the current configuration, or any of the alternative or previously blocked configurations; or backup to previous points in the parse to examine more closely the path taken. The break package exec is

BREAK1 (the LISP Break executive) augmented with some special functions and BREAKMACROS. Since the user is talking to BREAK1, he can use any of the LISP break commands or execute any LISP functions as well as the special commands described below. He can also use the special commands while inside of a break caused by having broken one of his functions or typing Control-H or Control-B.

How to Get into a Break

Whenever the trace package prints a line of tracing information, and the variable PAUSEFLAG has a non-NIL value, the trace package will wait for the user to indicate whether to continue or break. A break is caused by typing PAUSECHAR (initially ","). Continuation is caused by typing CONTINUECHAR (initially "."). All other characters are ignored. If PAUSECHAR is typed, BREAK1 is entered. The parsing is resumed by using one of the Break exiting commands, or by using one of the special commands described below. Note: "." is equivalent to the Break command "OK".

Grammar Break Commands

Printing Out Parsing Information:

The following commands and functions are provided to print out information associated with a configuration.

1) CF - a Break command which prints out the present status of the currently active configuration.

2) PPCF(n) - prints out the status of configuration number n.

Note: Both CF and PPCF only print non-NIL information about a configuration. Also PRINTLEVEL is set to 4 when debugging. It can be reset to a higher (or lower) number if the user wants more (or less) information printed.

3) PT - a Break command which tree prints (PPTT - see below) the current structure (*). This is most useful after a POP to examine the structure which was POPped.

4) PPTT(x) - prints the structure x in a tree format without parentheses.

5) CFARRAYDUMP(ST END) - dumps the contents of the configuration array from configuration number ST to configuration number END. If ST is NIL, 0 is used. If END is NIL, the largest configuration FREECF#, is used.

Commands to Back up the Parser

The following commands are used to change the flow of control of the parser while debugging. In order to use AGAIN or BACKUP, the parser must be run in PATH mode, which saves a new configuration each time an arc is taken.

1) AGAIN - a break command which restarts the current configuration, i.e. goes back to the most recent arc transition and starts again. The effect is to redo the current arc. If the user discovers that this did not back up far enough, he can use the command BACKUP.

2) BACKUP - a break command which restarts the configuration which led to the current one. BACKUP may be invoked successively to back up more than one arc transition.

3) ABORT - a break command which ABORTs the current configuration. The next active configuration will be taken from the ALTS list.

Note: AGAIN and BACKUP are useful if an arc is taken (or not taken) when it should not have been (or should have been). The predicates or functions involved in the offending arc test can be broken (using the LISP function BREAK) and then AGAIN or BACKUP can be called to redo the arc.

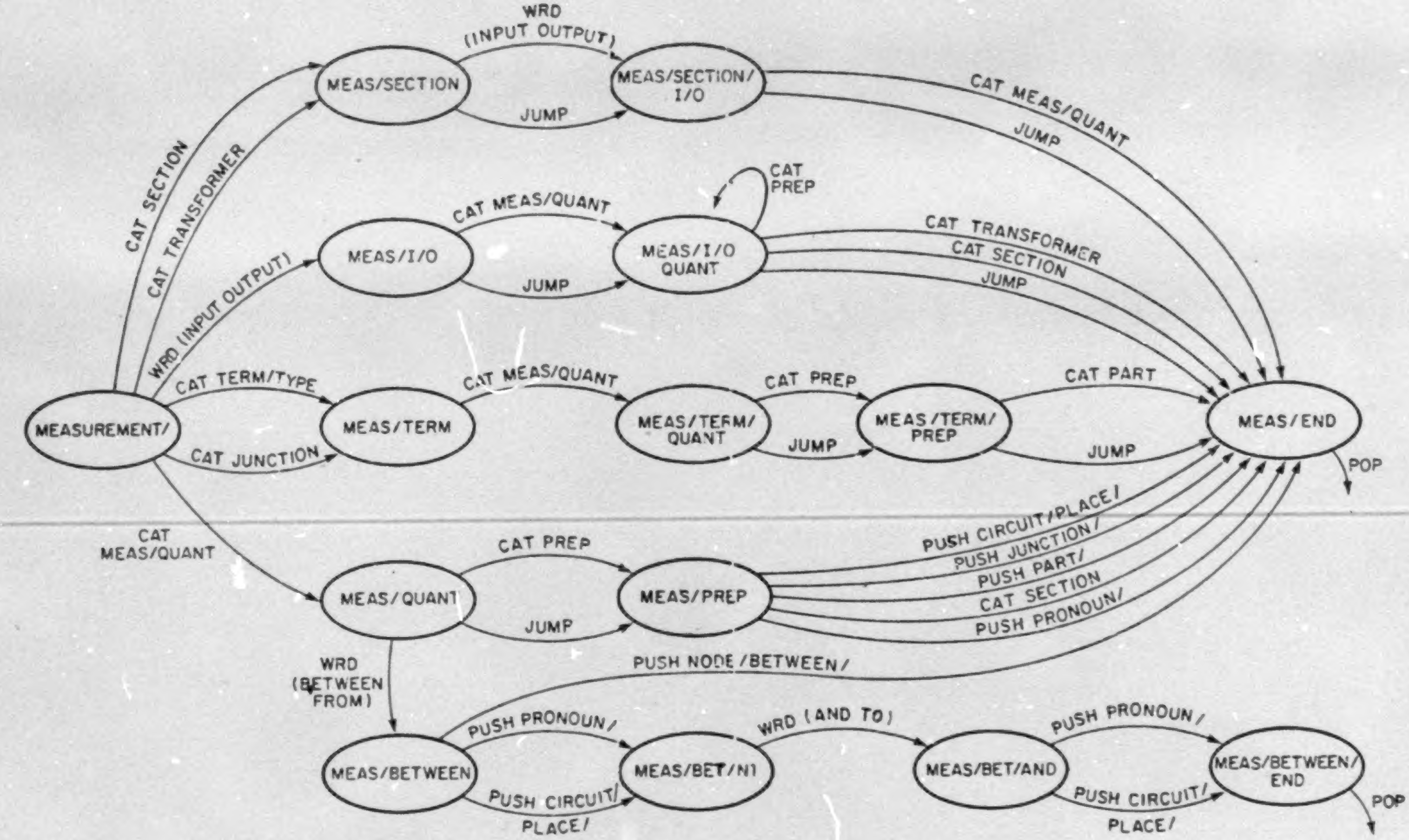
4) FIRE(n) - aborts the current configuration and starts the configuration n. If n is on the ALTS list, the ALTS list is POPped to the configuration before n.

5) PARSER(n) - recursively invokes the parser on configuration n. This provides a way of exploring one of the configurations on the ALTS list or returning to a (much) earlier configuration. Note: After PARSER returns, the user is still in the same place with respect to the current parse (except that he may have fewer configurations left, his alternative lists may have been altered and his WFST may contain more entries.)

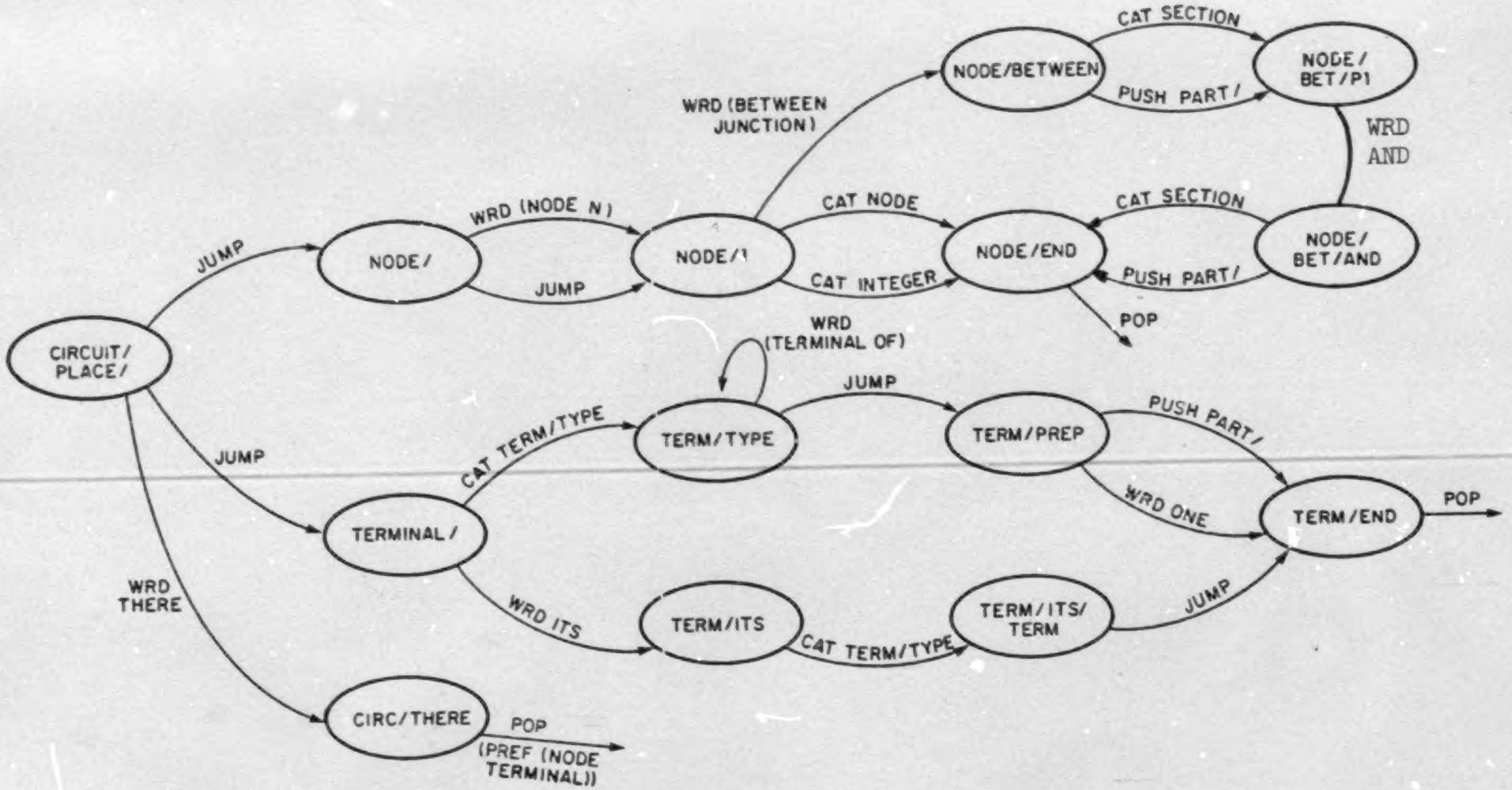
Appendix G

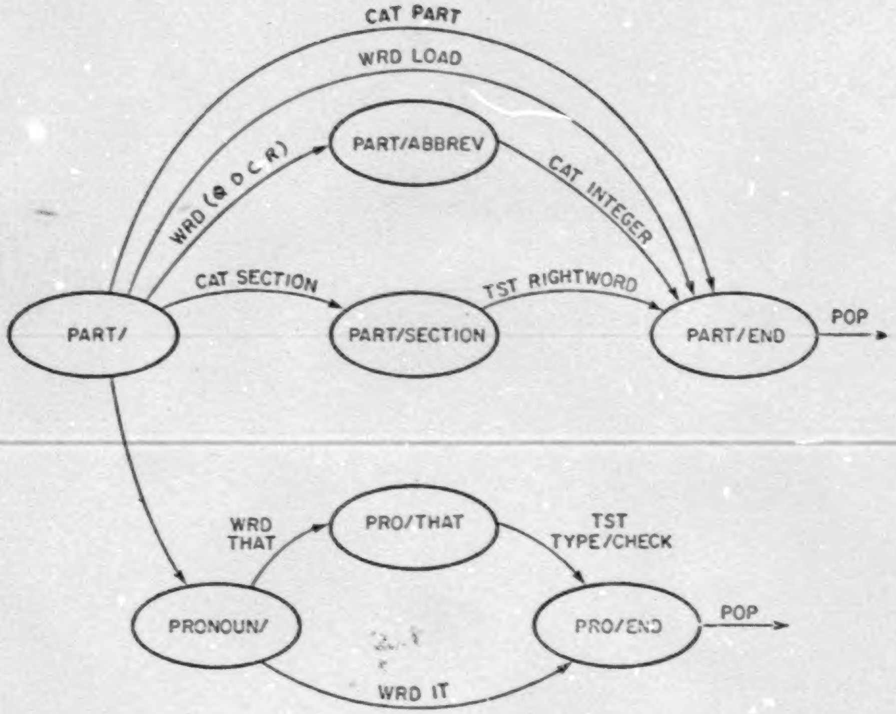
ATN Description of Part of the SOPHIE Semantic Grammar

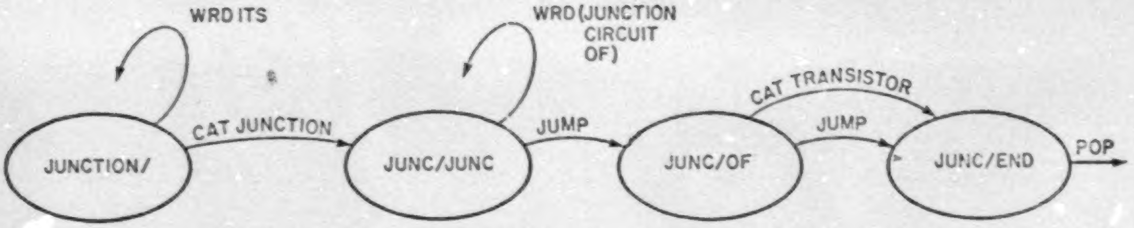
This appendix gives an ATN description of the same subset of the language as presented in Appendix A. Of the 24 rules listed in Appendix A, 15 became "syntactic" categories, 3 were incorporated into other networks and 6 remained non-terminals. The first section presents the ATN in its graphic form. The second section presents the ATN as it is input to the compiler.


MEASUREMENT/
CAT SECTION
CAT TRANSFORMER
WRD (INPUT OUTPUT)
CAT TERM/TYPE
CAT JUNCTION
CAT MEAS/QUANT
MEAS/SECTION
WRD (INPUT OUTPUT)
JUMP
MEAS/SECTION/ I/O
CAT MEAS/QUANT
JUMP
MEAS/I/O
CAT MEAS/QUANT
JUMP
MEAS/I/O QUANT
CAT PREP
CAT TRANSFORMER
CAT SECTION
JUMP
MEAS/TERM
CAT MEAS/QUANT
MEAS/TERM/ QUANT
CAT PREP
JUMP
MEAS/TERM/ PREP
CAT PART
JUMP
MEAS/END
POP
MEAS/QUANT
CAT PREP
JUMP
MEAS/PREP
PUSH CIRCUIT/PLACE/
PUSH JUNCTION/
PUSH PART/
CAT SECTION
PUSH PRONOUN/
PUSH NODE/BETWEEN/
WRD (BETWEEN FROM)
MEAS/BETWEEN
PUSH PRONOUN/
PUSH CIRCUIT/ PLACE/
MEAS/BET/N1
WRD (AND TO)
MEAS/BET/AND
PUSH PRONOUN/
PUSH CIRCUIT/ PLACE/
MEAS/BETWEEN/ END
POP

Graphic Form of Semantic ATN


CIRCUIT/ PLACE/
JUMP
NODE/
WRD (NODE N)
JUMP
NODE/1
WRD (BETWEEN JUNCTION)
NODE/BETWEEN
CAT SECTION
PUSH PART/
NODE/ BET/P1
WRD AND
CAT NODE
CAT INTEGER
NODE/END
CAT SECTION
PUSH PART/
NODE/ BET/AND
POP
JUMP
TERMINAL/
CAT TERM/TYPE
TERM/TYPE
WRD (TERMINAL OF)
JUMP
TERM/PREP
PUSH PART/
WRD ONE
TERM/END
POP
WRD ITS
TERM/ITS
CAT TERM/TYPE
TERM/ITS/ TERM
JUMP
WRD THERE
CIRC/THERE
POP (PREF (NODE TERMINAL))


CAT PART
WRD LOAD
PART/ABBREV
WRD (B O C R)
CAT INTEGER
CAT SECTION
TST RIGHTWORD
PART/
PART/SECTION
PART/END
POP
WRD THAT
PRO/THAT
TST TYPE/CHECK
PRONOUN/
PRO/END
POP
WRD IT


WRD ITS
WRD (JUNCTION CIRCUIT OF)
CAT TRANSISTOR
CAT JUNCTION
JUMP
JUMP
JUNCTION/
JUNC/JUNC
JUNC/OF
JUNC/END
POP

```
(MEASUREMENT/
   (GROUP
      (CAT SECTION T
           (SETR WHERE *)
           (TO MEAS/SECTION))
      (WRD (INPUT OUTPUT) T
           (SETR I/O LEX)
           (TO MEAS/I/O))
      (CAT MEAS/QUANT T
           (SETR QUANT *)
           (TO MEAS/QUANT))
      (CAT JUNCTION T
           (SETR TERM *)
           (TO MEAS/TERM))
      (CAT TERM/TYPE T
           (SETR TERM *)
           (TO MEAS/TERM))
      (CAT TRANSFORMER T
           (SETR WHERE *)
           (TO MEAS/SECTION))))

(MEAS/SECTION
   (GROUP
      (WRD (INPUT OUTPUT) T
           (SETR I/O *)
           (TO MEAS/SECT/I/O))
      (JUMP MEAS/SECT/I/O T)))

(MEAS/SECT/I/O
   (GROUP
      (CAT MEAS/QUANT T
           (SETR QUANT *)
           (TO MEAS/END))
      (JUMP MEAS/END (GETR I/O))))

(MEAS/I/O
   (GROUP
      (CAT MEAS/QUANT T
           (SETR QUANT *)
           (TO MEAS/I/O/QUANT))
      (JUMP MEAS/I/O/QUANT T)))

(MEAS/I/O/QUANT
   (GROUP
      (CAT PREP T
           (TO MEAS/I/O/QUANT))
      (CAT TRANSFORMER T
           (SETR WHERE *)
           (TO MEAS/END))
      (CAT SECTION T
           (SETR WHERE *)
           (TO MEAS/END))
      (JUMP MEAS/END T)))

(MEAS/TERM
   (CAT MEAS/QUANT T
        (SETR QUANT *)
        (TO MEAS/TERM/Q)))

(MEAS/TERM/Q
   (GROUP
      (CAT PREP T
           (TO MEAS/TERM/PREP))
      (JUMP MEAS/TERM/PREP T)))
```

```
(MEAS/TERM/PREP
   (GROUP
      (CAT PART T
           (SETR WHERE (BUILDQ (+ *)
          TERM))
           (TO MEAS/END))
      (JUMP MEAS/END T
           (SETR WHERE (BUILDQ (+ (PREF  ))
          TERM
          (PART/RANGE TERM))))))

(MEAS/QUANT
   (GROUP
      (WRD (ON OF) T
           (SETRQ CLASSES (PART TERMINAL JUNCTION NODE SECTION))
           (TO MEAS/PREP))
      (WRD AT T
           (SETRQ CLASSES (NODE TERMINAL))
           (TO MEAS/PREP))
      (WRD (BETWEEN FROM) T
           (TO MEAS/BETWEEN))
      (WRD ACROSS T
           (SETRQ CLASSES (PART JUNCTION))
           (TO MEAS/PREP))
      (WRD IN T
           (SETRQ CLASSES (PART TERMINAL JUNCTION SECTION))
           (SETRQ I/O INPUT)
           (TO MEAS/PREP))
      (WRD THROUGH T
           (SETRQ CLASSES (PART TERMINAL JUNCTION SECTION))
           (TO MEAS/PREP))
      (WRD (OUT FROM) T
           (SETRQ CLASSES (SECTION))
           (SETRQ I/O OUTPUT)
           (TO MEAS/PREP))
      (JUMP MEAS/PREP T))
   (POP (BUILDQ (REFERENCE ((QUANT)
       +))
 QUANT)
       T))

(MEAS/PREP
   (PUSH CIRCUIT/PLACE/ T
        (SENDRQ NOPRO T)
        (SETR WHERE *)
        (TO MEAS/END))
   (PUSH JUNCTION/ T
        (SENDRQ NOPRO T)
        (SETR WHERE *)
        (TO MEAS/END))
   (PUSH PART/ T
        (SENDRQ NOPRO T)
        (SETR WHERE *)
        (TO MEAS/END))
   (CAT SECTION T
        (SENDRQ NOPRO T)
        (SETR WHERE *)
        (TO MEAS/END))
   (PUSH PRONOUN/ (GETR CLASSES)
        (SENDR TYPES (GETR CLASSES))
        (SETR WHERE *)
        (TO MEAS/END)))

(MEAS/END
   (POP (BUILDQ (MEASURE + + +)
  QUANT WHERE I/O)
       T))

(MEAS/BETWEEN
   (PUSH PRONOUN/ T
        (SENDRQ TYPES (NODE TERMINAL))
        (SETR NODE1 *)
        (TO MEAS/BET/N1))
   (PUSH CIRCUIT/PLACE/ T
        (SETR NODE1 *)
        (TO MEAS/BET/N1))
   (PUSH NODE/BET T
        (SETR WHERE *)
        (TO MEAS/END))
   (WRD OUTPUT T
        (TO MEAS/BET/OUT)))

(MEAS/BET/N1
   (WRD (TO AND) T
        (TO MEAS/BET/AND)))

(MEAS/BET/AND
   (PUSH CIRCUIT/PLACE/ T
        (SETR NODE2 *)
        (TO MEAS/BET/END)))

(MEAS/BET/END
   (POP (BUILDQ (MEASURE + + +)
 QUANT NODE1 NODE2)
       T))

(CIRCUIT/PLACE/
   (JUMP TERMINAL/ T)
   (JUMP NODE/ T)
   (WRD THERE T
        (SETR POPVAL (BUILDQ (PREF (NODE TERMINAL))))
        (TO POP/VAL/)))

(NODE/
   (GROUP
      (WRD (NODE N) T
           (TO NODE/1))
      (JUMP NODE/1 T)))

(NODE/1
   (GROUP
      (WRD (BETWEEN JUNCTION) T
           (TO NODE/BET))
      (CAT NODE T
           (SETR NODE *)
           (TO NODE/END))
      (CAT INTEGER (AND (IGREATERP * -1)
   (ILESSP * 27))
           (SETR NODE (PACK (LIST (QUOTE N)
      *)))
           (TO NODE/END))))

(NODE/BET
   (GROUP
      (WRD OF T
           (TO NODE/BET))
      (CAT SECTION T
           (SETR PART1 *)
           (TO NODE/BET/P1)))
   (PUSH PART/ T
          (SETR PART1 *)
          (TO NODE/BET/P1)))

(NODE/BET/P1
   (WRD AND T
          (TO NODE/BET/AND)))

(NODE/BET/AND
   (PUSH PART/ T
          (SETR NODE (BUILDQ (NODE/BETWEEN + *)
        PART1))
          (TO NODE/END))
   (CAT SECTION T
          (SETR NODE (BUILDQ (NODE/BETWEEN + *)
        PART1))
          (TO NODE/END)))

(NODE/END
   (POP (GETR NODE)
        T))

(TERMINAL/
   (GROUP
      (CAT TERM/TYPE T
           (SETR TERM/TYPE *)
           (TO TERM/TYPE))
      (WRD ITS T
           (TO TERM/ITS))
      (WRD OUTPUT T
           (TO TERM/OP))))

(TERM/TYPE
   (GROUP
      (WRD TERMINAL T
           (TO TERM/TYPE/2))
      (JUMP TERM/TYPE/2 T)))

(TERM/PREP
   (PUSH PART/ T
          (SETR PART *)
          (TO TERM/TERM))
   (WRD ONE T
          (SETR PART (BUILDQ (PREF   )
      (PART/RANGE TERM/TYPE)))
          (TO TERM/TERM))
   (JUMP TERM/TERM T
          (SETR PART (BUILDQ (PREF   )
      (PART/RANGE TERM/TYPE)))))

(TERM/TERM
   (POP (BUILDQ (+ +)
  TERM/TYPE PART)
        T))

(TERM/ITS
   (CAT TERM/TYPE T
          (SETR TERM/TYPE *)
          (TO TERM/ITS/END)))

(TERM/ITS/END
   (POP (BUILDQ (+ (PREF   ))
  TERM/TYPE
  (PART/RANGE TERM/TYPE))
        T))
```

```
(PART/
   (GROUP
      (CAT PART T
           (SETR PART *)
           (TO PART/END))
      (WRD (Q R D C) T
           (SETR TYPE *)
           (TO PART/ABBEV))
      (WRD LOAD T
           (SETRQ PART LOAD)
           (TO PART/END))
      (CAT SECTION T
           (SETR SECTION *)
           (SETRQ CLASSES (CAPACITOR DIODE RESISTOR TRANSISTOR
         ZENER/DIODE TRANSFORMER))
           (TO PART/SECTION))
      (JUMP PRONOUN/ T
           (SETRQ TYPES (PART)))))

(PART/ABBEV
   (CAT INTEGER T
        (SETR PART (PACK (LIST (GETR TYPE)
          *)))
        (TO PART/END)))

(PART/SECTION
   (TST RIGHT/TYPE (MEMB LEX (GETR CLASSES))
        (SETR PART (BUILDQ (FINDPART +  )
      SECTION LEX))
        (TO PART/END)))

(PART/END
   (POP (GETR PART)
       T))

(PRONOUN/
   (GROUP
      (WRD IT T
           (TO PRO/END))
      (WRD THAT T
           (TO PRO/THAT))))

(PRO/THAT
   (TST TYPE/CHECK (MEMB LEX (GETR TYPES))
        (SETR TYPES (LIST LEX))
        (TO PRO/END)))

(PRO/END
   (POP (BUILDQ (PREF +)
  TYPES)
       T))

(JUNCTION/
   (GROUP
      (CAT JUNCTION T
           (SETR JUNCTION *)
           (TO JUNC/JUNC))
      (WRD ITS (NULLR NOPRO)
           (TO JUNCTION/))))

(JUNC/JUNC
   (GROUP
      (WRD (JUNCTION CIRCUIT OF) T
           (TO JUNC/JUNC))
      (JUMP JUNC/OF T)))
```

```
(JUNC/OF
   (GROUP
      (CAT TRANSISTOR T
           (SETR TRAN *)
           (TO JUNC/END))
      (JUMP JUNC/END (NULLR NOPRO)
           (SETR TRAN (LIST (QUOTE PREF)
       (QUOTE (TRANSISTOR)))))))

(JUNC/END
   (POP (BUILDQ (+ +)
  JUNCTION TRAN)
       T))
```

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